Searches for Higgs and New Phenomena at CDF

The Tevatron Connection

June 24-25, 2005

Song Ming Wang

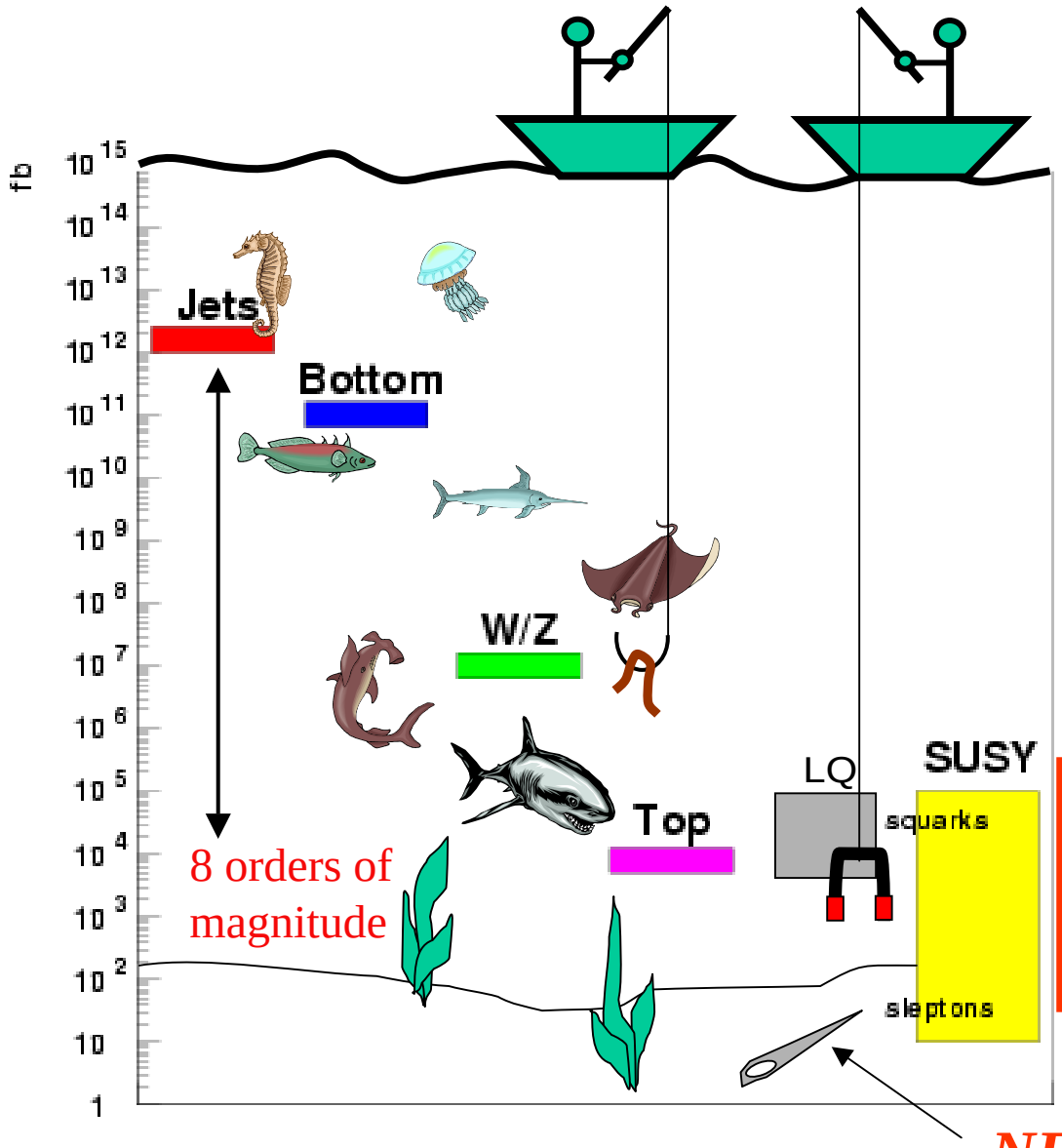
University of Florida

On behalf of CDF Collaboration

Outline

- Detecting New Physics at CDF
- New CDF Results on the Searches for :
  - New Phenomena w/ Leptons in Final States :
    - High Mass Resonances
    - SUSY in Multi-lepton Signature
    - Extra Dimensions
  - New Physics in MET+Jets
  - Higgs
- Summary

Searches for New Physics



- Predicted rates for new physics are LOW !!!

To search for New Physics is like :

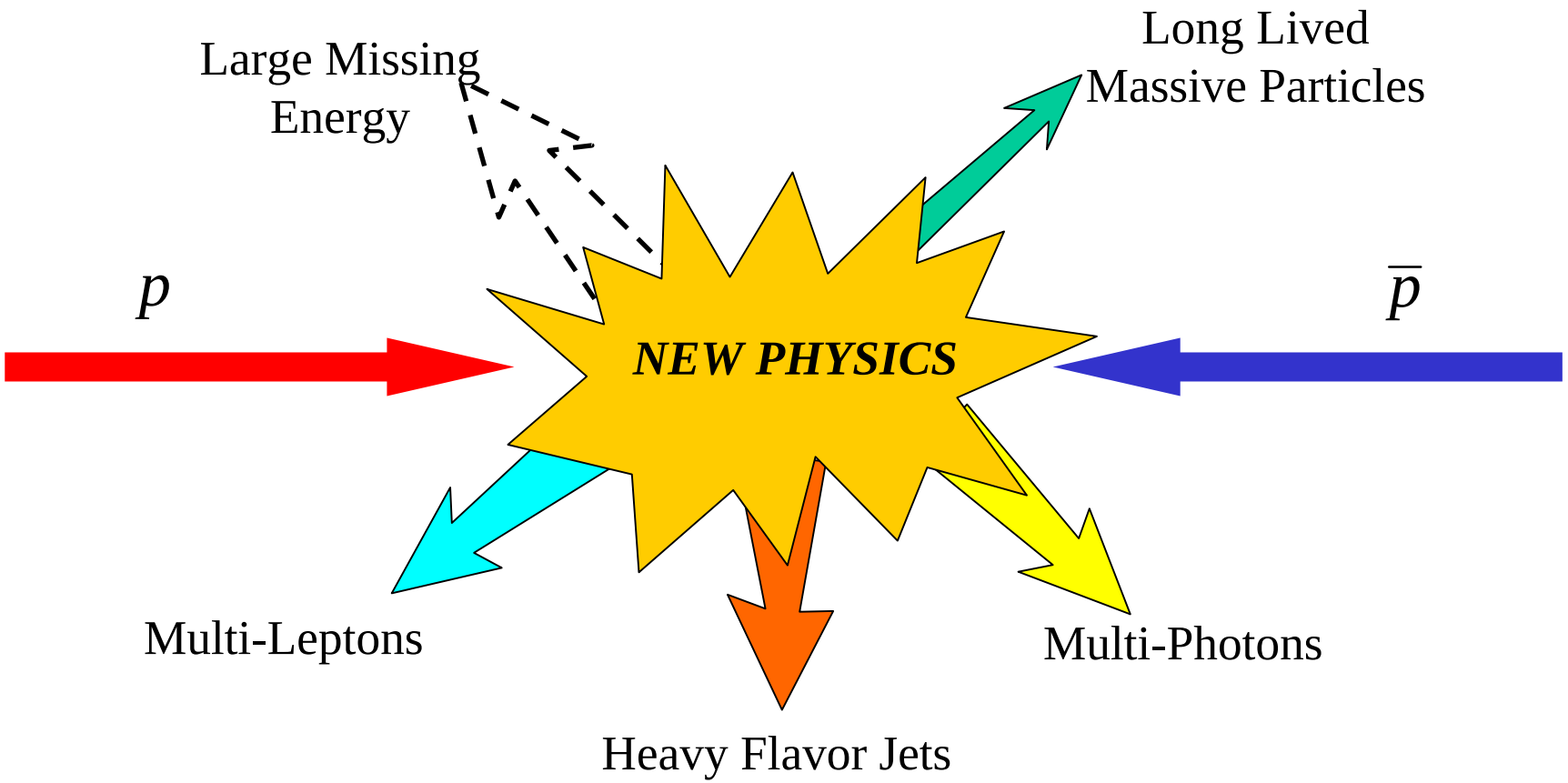
- "searching for a needle in a hay stack" (western version)
- Or
- "searching for a needle in the ocean" (eastern version)

- **Need to look for distinctive signature to suppress SM background**

NEW PHYSICS !!!

New Phenomena Searches at CDF

- New physics can manifest itself in several rare final state signatures of p-pbar collisions



New Phenomena Searches at CDF

Experimental Signatures

$l^{\pm}l^{\mp}, l^{\pm}l^{\pm}, ll', llll, l\nu, l\nu l\nu$

$lljj, l\nu jj, \nu\nu jj, llbb, l\nu bb, \nu\nu bb$

$l\gamma + \mathrm{X}$

$\gamma\gamma, \gamma + \mathrm{MET}, \gamma\gamma + \mathrm{MET}$

$jets + \mathrm{MET}$

$bb / cc + \mathrm{MET}, bbbb + \mathrm{MET}$

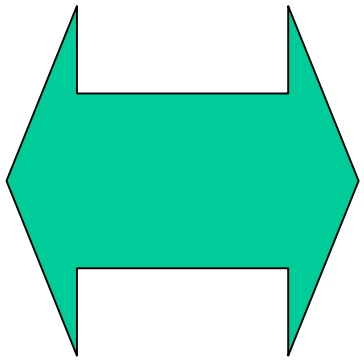
$lll + \mathrm{MET}, bbll + \mathrm{MET}$

$\gamma + b / c + \mathrm{MET}$

long-lived particles

.

.



New Phenomena

W', Z'

Extra Dimensions

Technicolor

Leptoquarks

Compositeness

Excited leptons

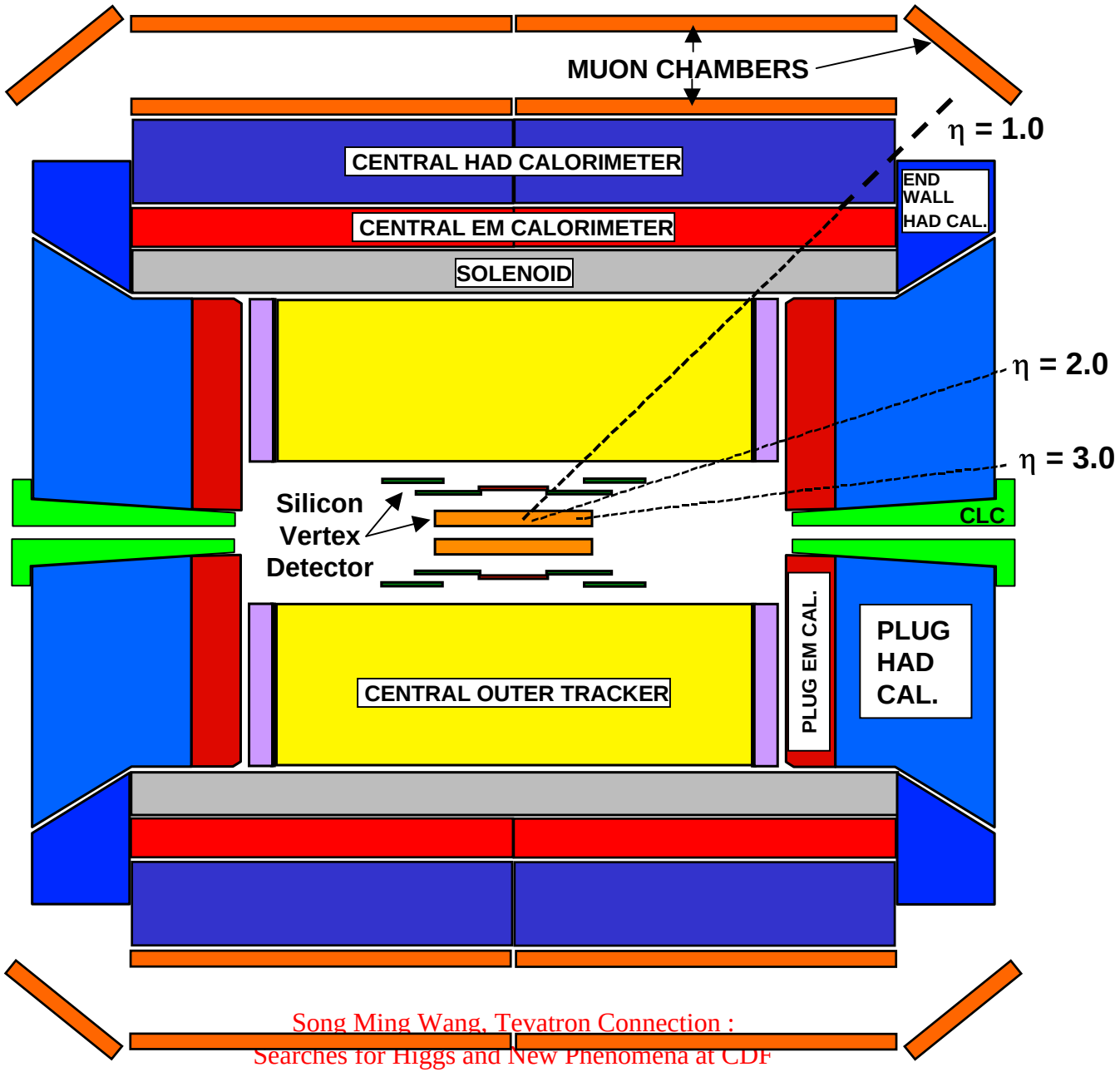
SUSY

Higgs

.

Need good understanding of the SM final states to **DISCOVER** *New Phenomena*

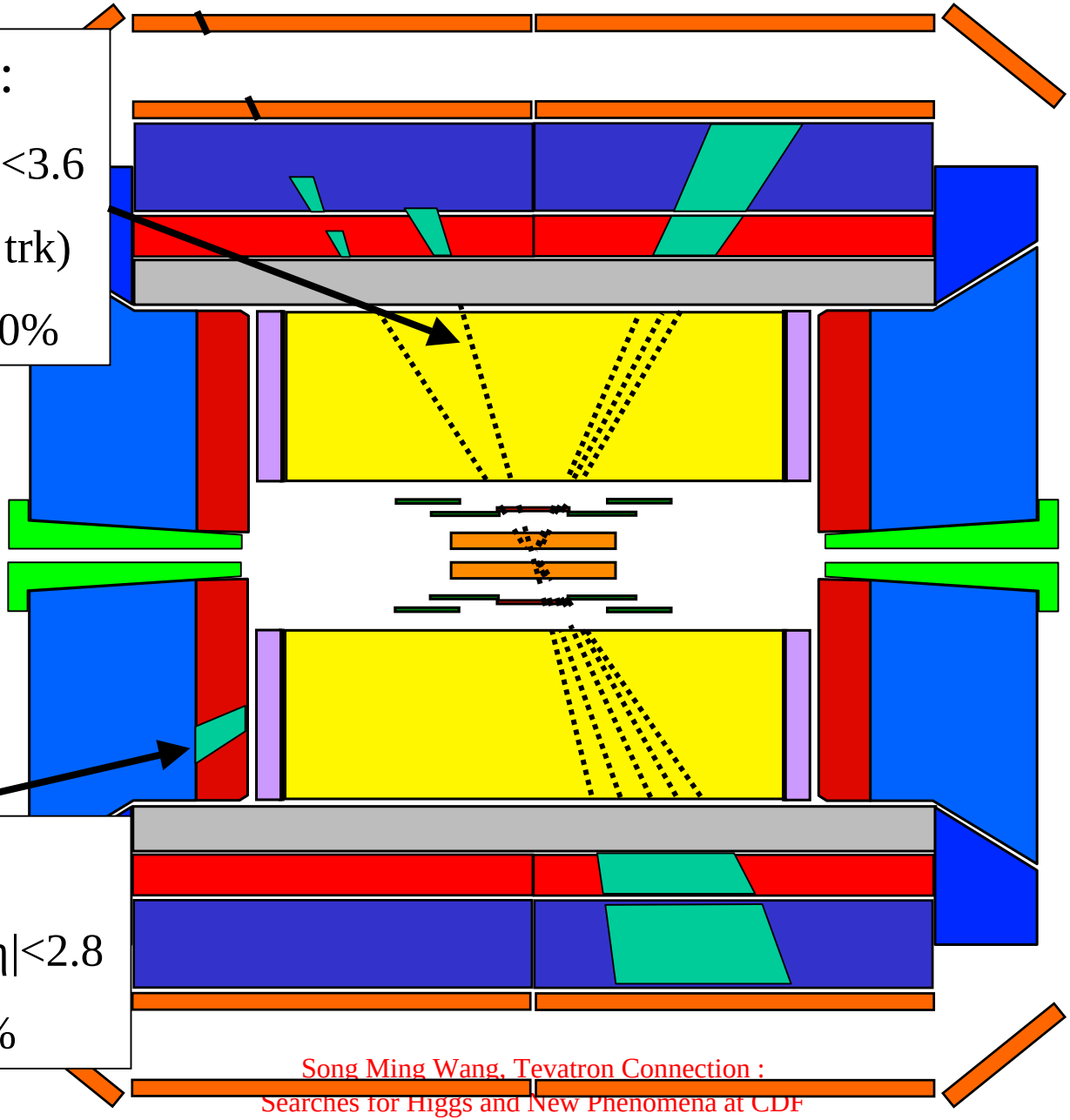
Measurement of Final State Objects with CDF



Measurement of Final State Objects with CDF

Electron ID :

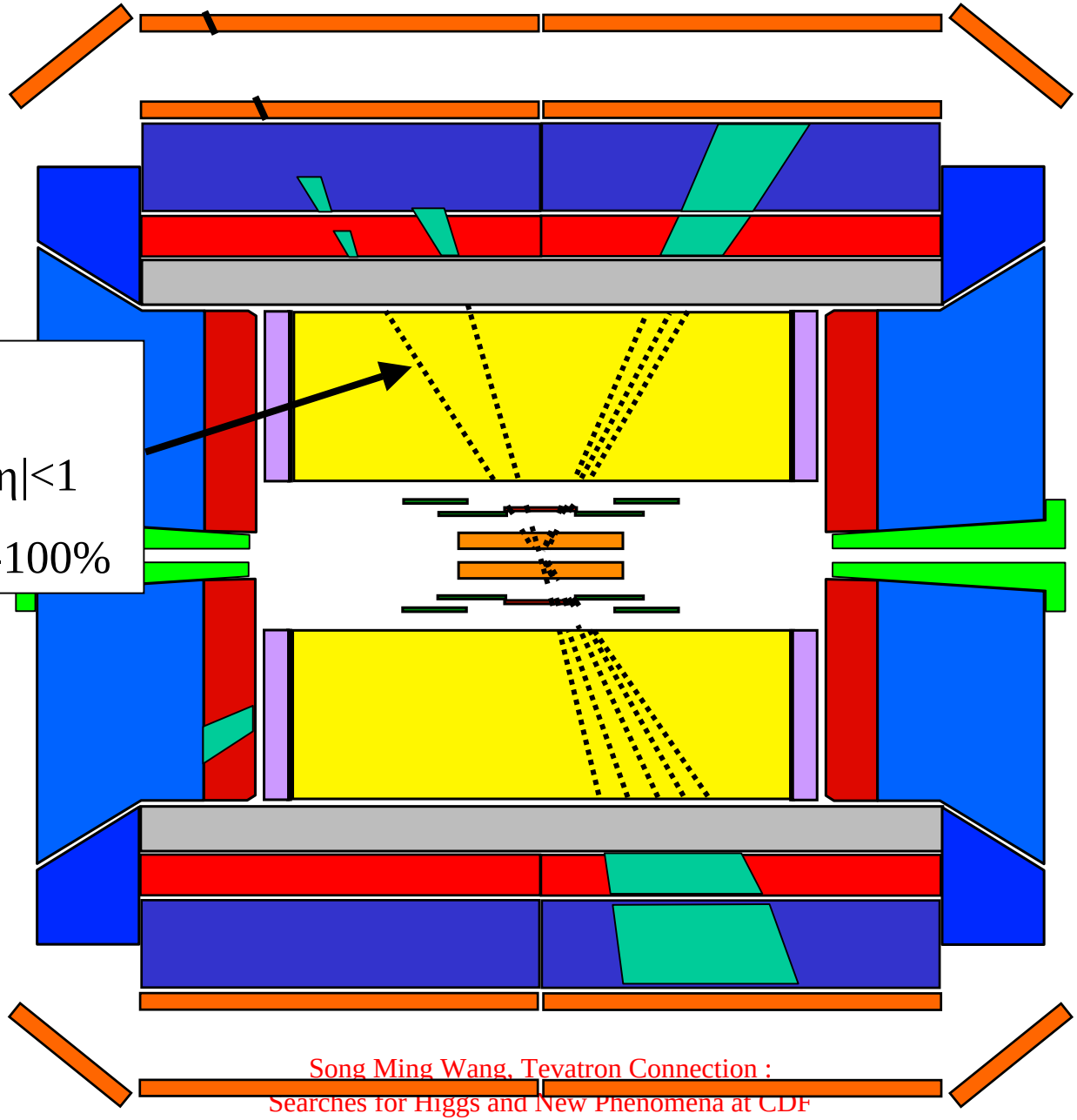
- Coverage : $|\eta|<3.6$
  - $|\eta|<2$ (w/ trk)
- ID eff. ~ 80-90%



Photon ID :

- Coverage : $|\eta|<2.8$
- ID eff. ~ 80%

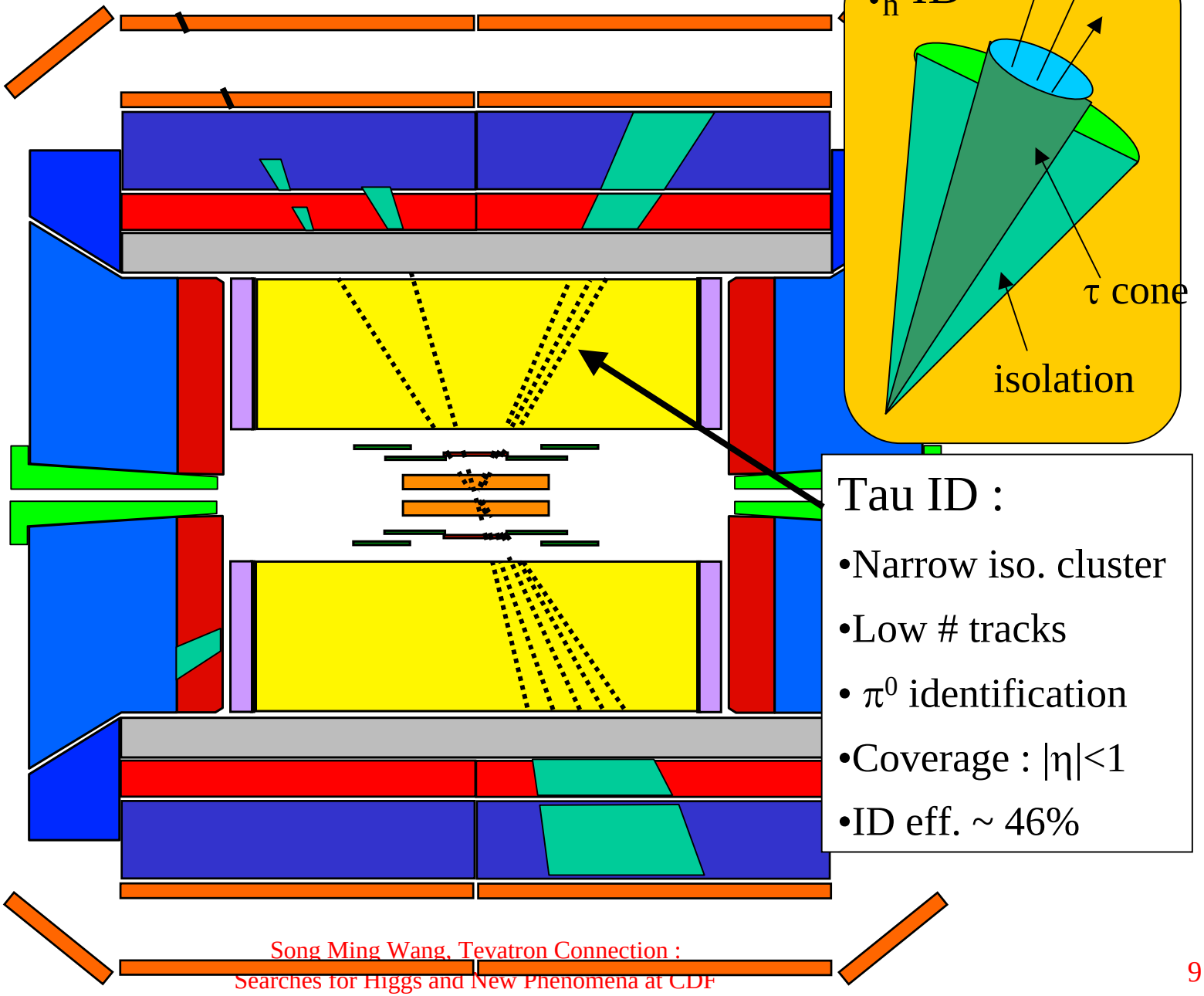
Measurement of Final State Objects with CDF



Muon ID :

- Coverage : $|\eta|<1$
- ID eff. ~ 90-100%

Measurement of Final State Objects with CDF



Tau ID :

- Narrow iso. cluster
- Low # tracks
- π^0 identification
- Coverage : $|\eta|<1$
- ID eff. ~ 46%

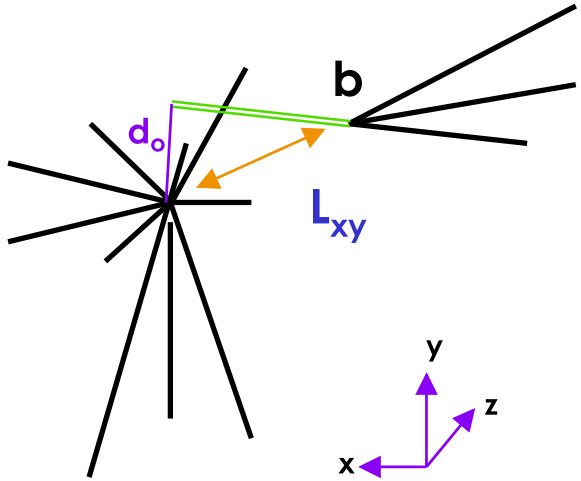
Measurement of Final State Objects with CDF

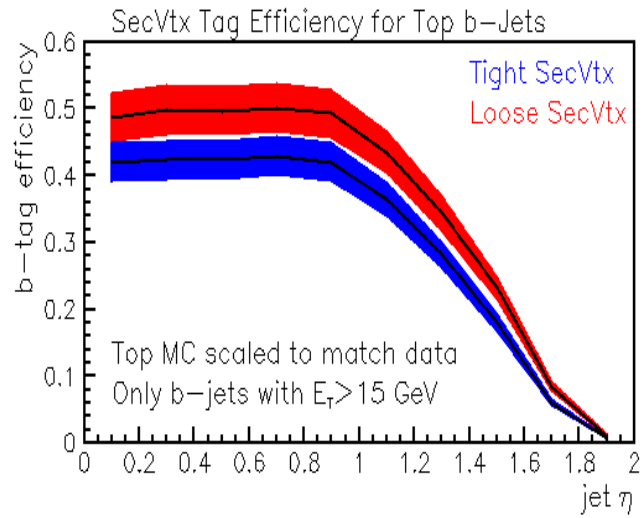
Jet ID :

- Cluster of CAL towers
- Coverage : $|\eta|<3.6$

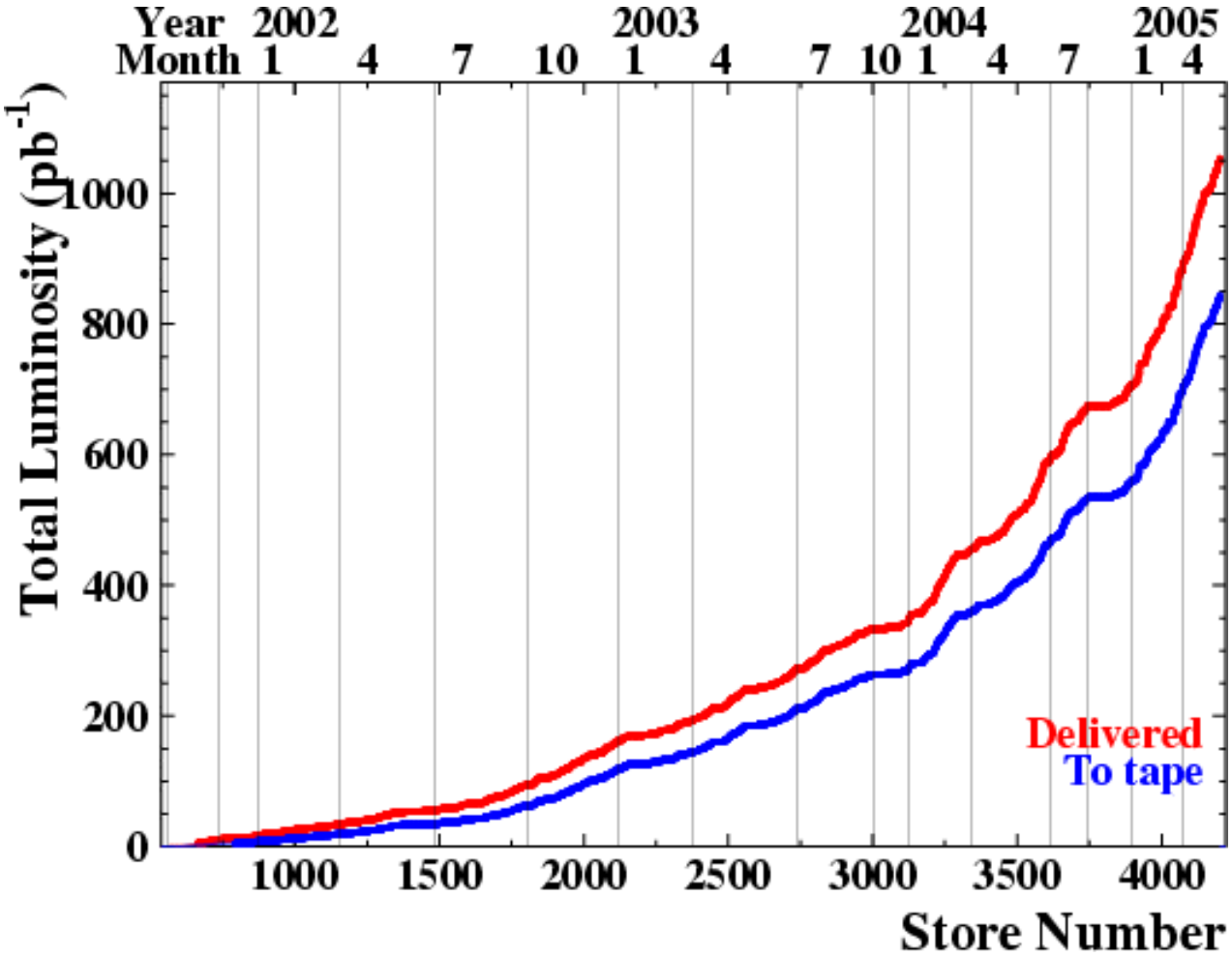
Heavy Flavor Jet Tagging :

- Id HF jets via semi-leptonic decay
  - Find soft lepton in jets
  - Coverage : $|\eta|<1$
- Id HF jets via finding displaced vertex
  - Coverage : $|\eta|<1.5$





Run II Data Collected at CDF



- Tevatron has delivered ~1.05 fb^{-1} to CDF
- CDF has collected about ~0.85 fb^{-1} data
- Results shown today are based on data samples of ~0.2 – 0.4 fb^{-1}

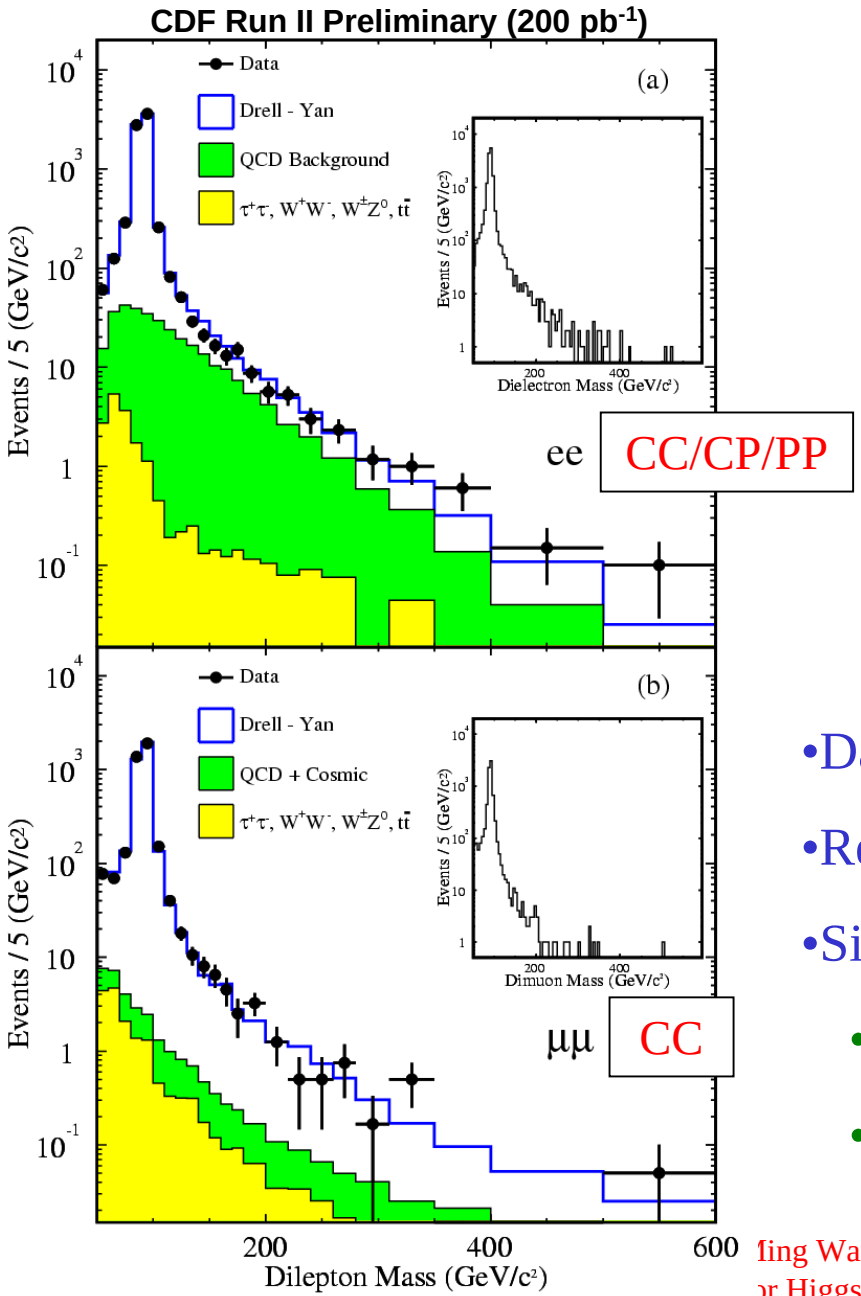
New Results from CDF

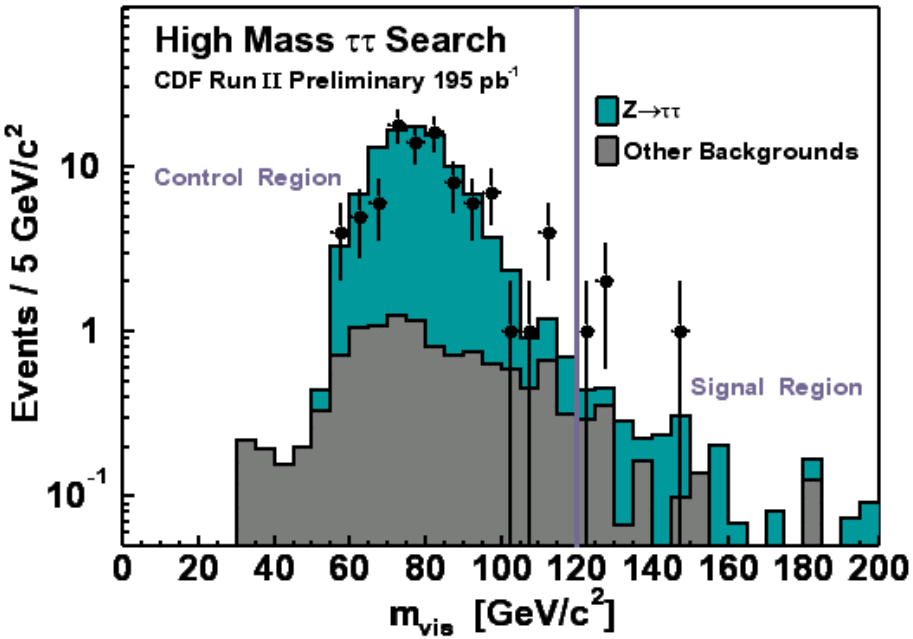
Topic	Analyses	L(pb^{-1})	Cover
High Mass	$Z' \rightarrow ee, \mu\mu, \tau\tau$	200/450	yes
	$W' \rightarrow e\nu$	205	yes
SUSY	Chargino/Neutralino in Trilepton	346/224	yes
	Scalar Neutrino (RPV)	344	yes
	Stop Pair Production (RPV)	200	no
	Stop Pair Production (RPC)	163	no
	Squark/Gluino Production	254	yes
Extra Dimension	ED in Multi-lepton	88	yes
Higgs	$WH \rightarrow l\nu bb$	319	yes
	$WH \rightarrow WWW^*$	194	no
	$\phi \rightarrow \tau\tau$	310	yes

Please visit: http://www-cdf.fnal.gov/physics/exotic/exotic.html

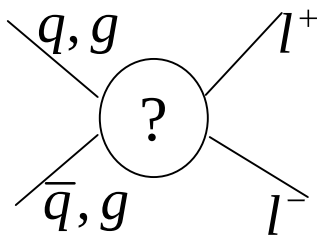
Search for High Mass Resonances w/ Leptons in Final States

Searches in High Mass Di-Lepton

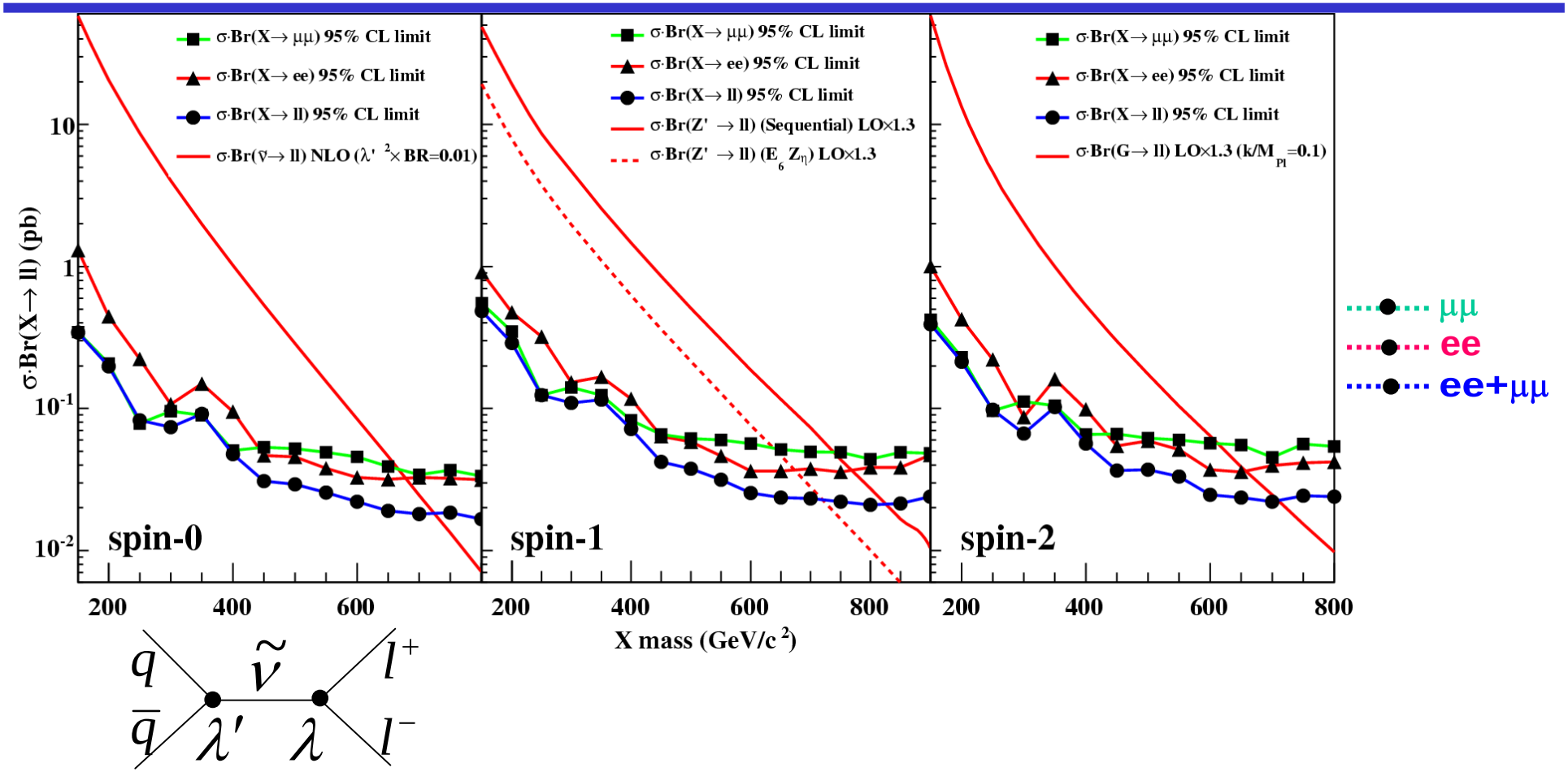




- Data samples ~ 200 pb-1
- Relatively "clean" channel
- Signature to explore many models
  - Z', SUSY(RPV), TC, RS graviton, ….
  - Look for resonance in the mass spect., or enhancement in the cross section



σ*Br Limit in Search for Mass Bumps (ee+μμ)



$M(\tilde{\nu}) > 725$ GeV
$(\lambda'^2 \times BR = 0.01)$

M(Z',seq)>825 GeV

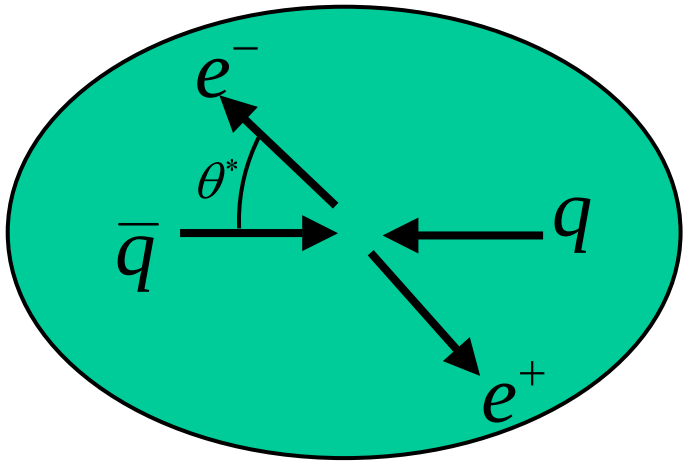
$M(E6, Z_\eta) > 720$ GeV

M(G) > 710 GeV
$(k/M_{Pl} = 0.1)$

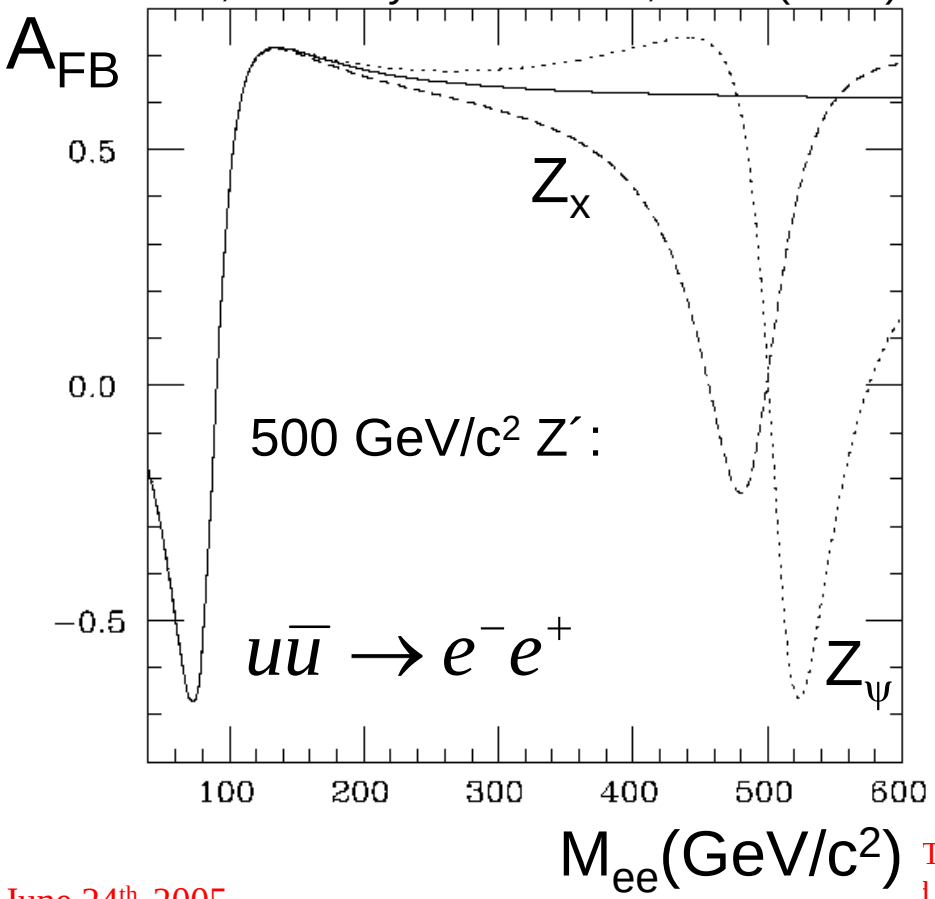
Limits at 95% C.L.

New Results in High Mass Di-Electron Search

- New analysis use 448 pb^{-1} data sample (~2x the previous e^+e^- analysis)
- Look at both the M(ee) and decay angle $\cos\theta^*$ for signal of new physics



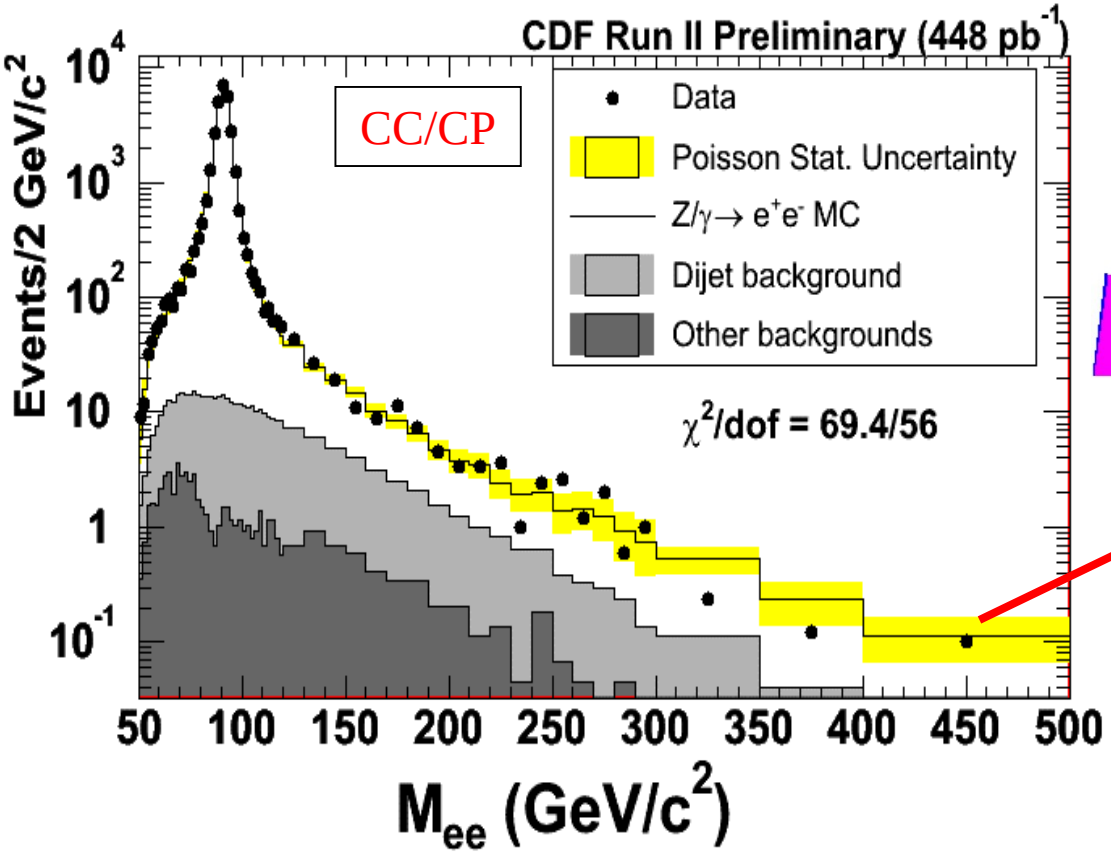
Rosner, J.L.: Phys. Rev. D 54, 1078 (1996)

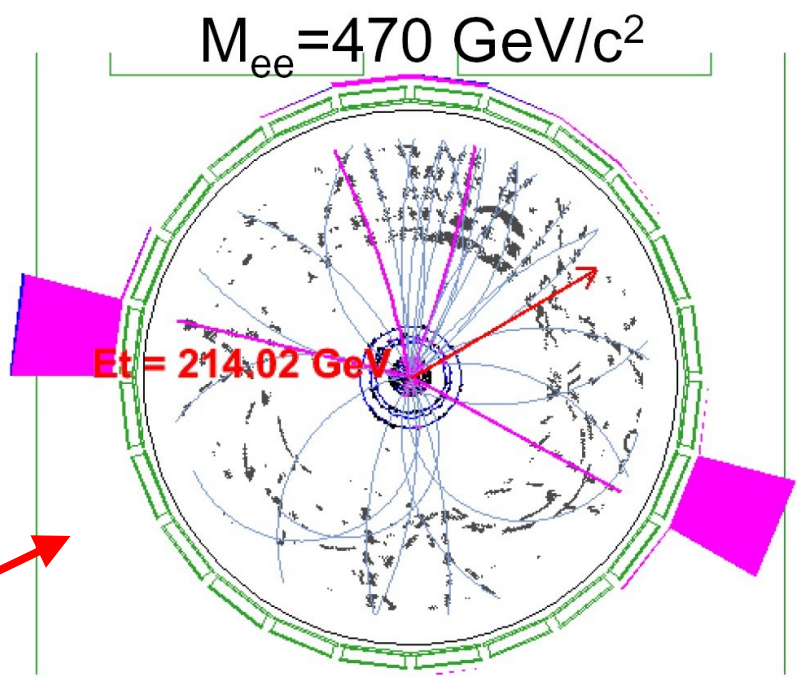


$$A_{FB} = \frac{d\sigma(\cos\theta^* > 0) - d\sigma(\cos\theta^* < 0)}{d\sigma(\cos\theta^* > 0) + d\sigma(\cos\theta^* < 0)}$$

- New resonance could interfere with γ and Z
- May observe the effect in A_{FB} distribution
- Can observe evidence below the Z' pole

New Results in High Mass Di-Electron Search



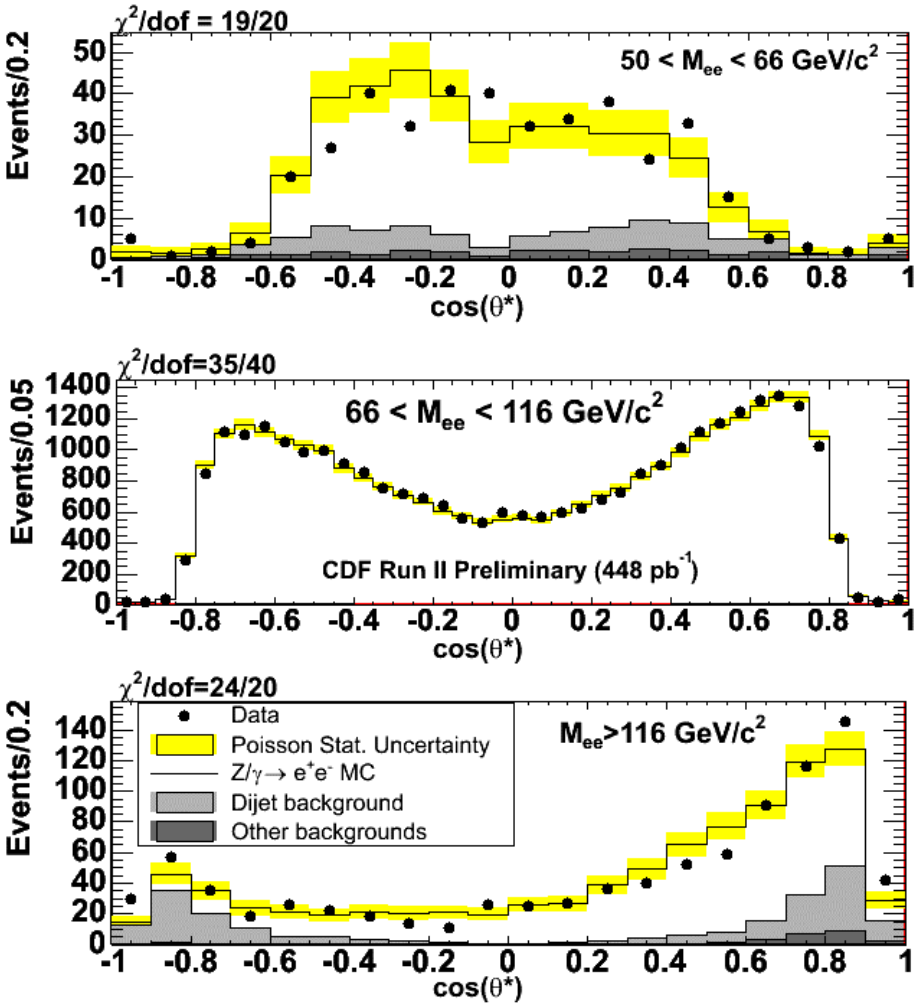


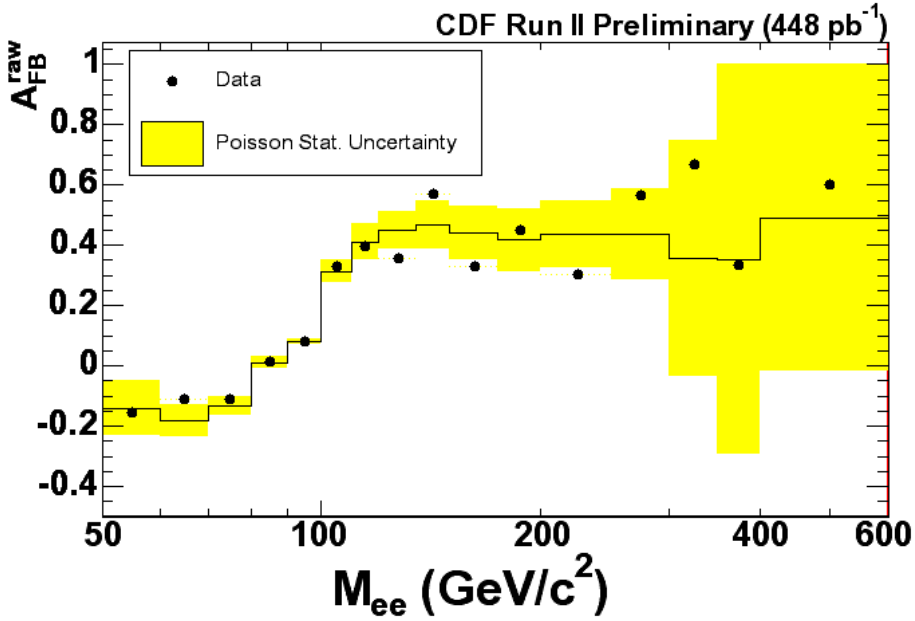
- Select events with 2 high Pt electrons
  - Central-Central, or Central-Plug
- Good agreement between data and prediction for full mass region

Events in Signal Region

	Data	Predicted
M>200 GeV	120	$125 \pm 11_{stat}$

New Results in High Mass Di-Electron Search





Limits in High Mass Di-Lepton Search

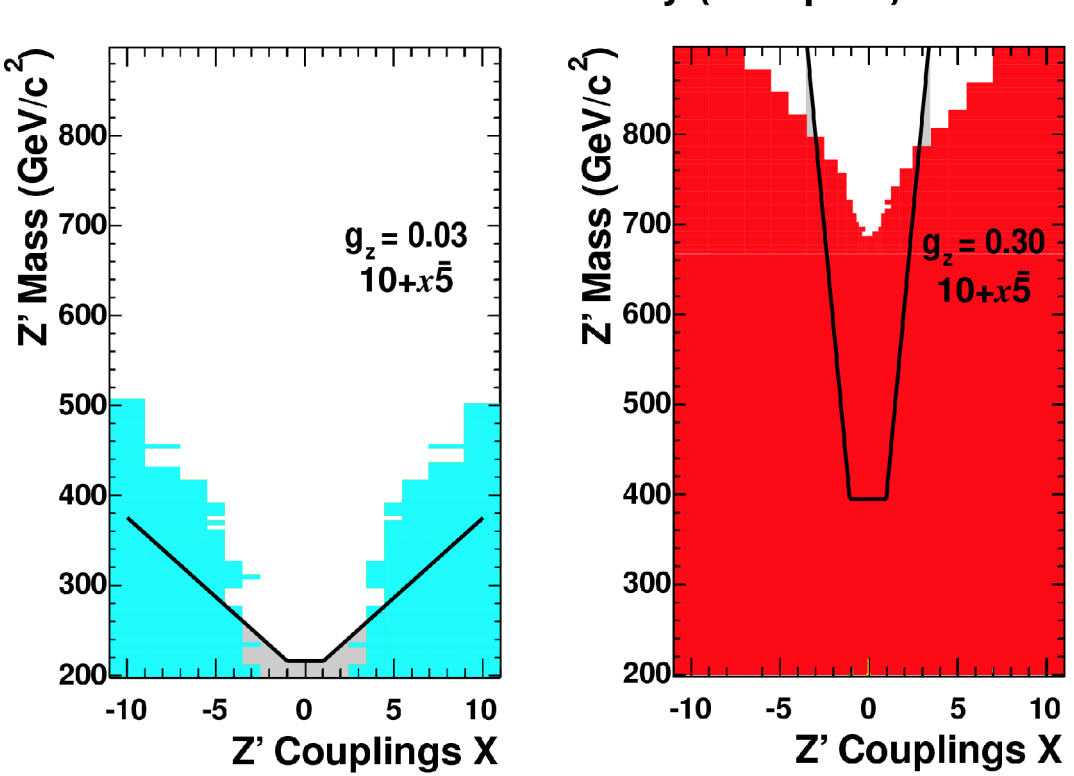
	CDF e^+e^- **448 pb^{-1}**	**CDF** ee + μμ **~200 pb^{-1}**	**CDF** ττ **~200 pb^{-1}**	**DØ** ee **~200 pb^{-1}**	**LEP2**
Seq. Z'	**845 GeV**	825 GeV	394 GeV	780 GeV	1.8 TeV
E6 Z_I	**625 GeV**	615 GeV		575 GeV	
E6 Z_χ	**720 GeV**	675 GeV		640 GeV	673 GeV
E6 Z_ψ	**690 GeV**	690 GeV		650 GeV	481 GeV
E6 Z_η	**715 GeV**	720 GeV		680 GeV	434 GeV

Limits in High Mass Di-Lepton Search

- Previous analyses focused on specific Z' models
- *Carena*, *Daleo*, *Dobrescu*, and *Tait*
  - Defines 4 general model classes (PRD 70:093009, 2004)
  - B-*x*L, q+*x*u, 10+*x*5, d-*x*u
  - Within each class, a Z' model is defined by :
    - mass $M_{Z'}$
    - strength g_z
    - parameter *x*
  - E6 motivated models :
    - 10+*x*5 models :
      - Z_η(*x*=-0.5, g_z=0.344)
      - Z_ψ(*x*=1, g_z=0.272)
      - Z_χ(*x*=-3, g_z=0.211)

Comparing CDF to LEP2:

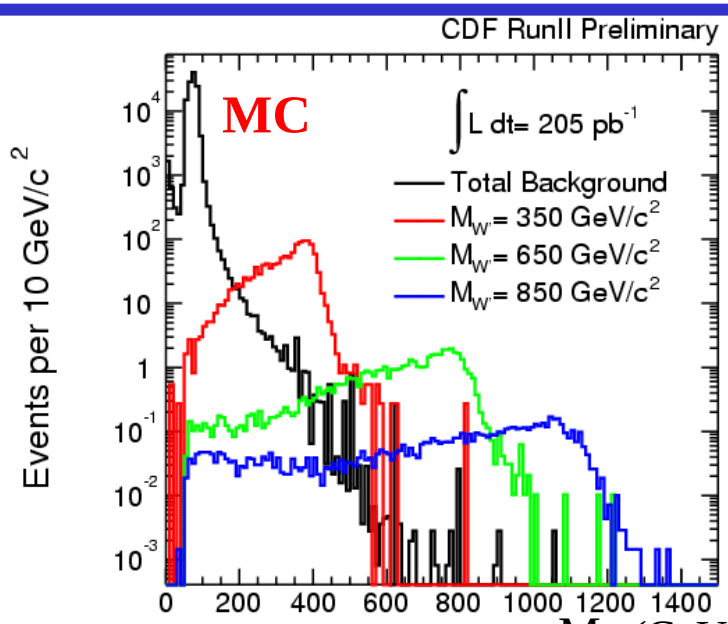
- CDF's sensitivity relative to LEP2 depends on model and *x*
- B-*x*L : sensitivity similar to LEP2
- 10+*x*5 : better sensitivity than LEP2

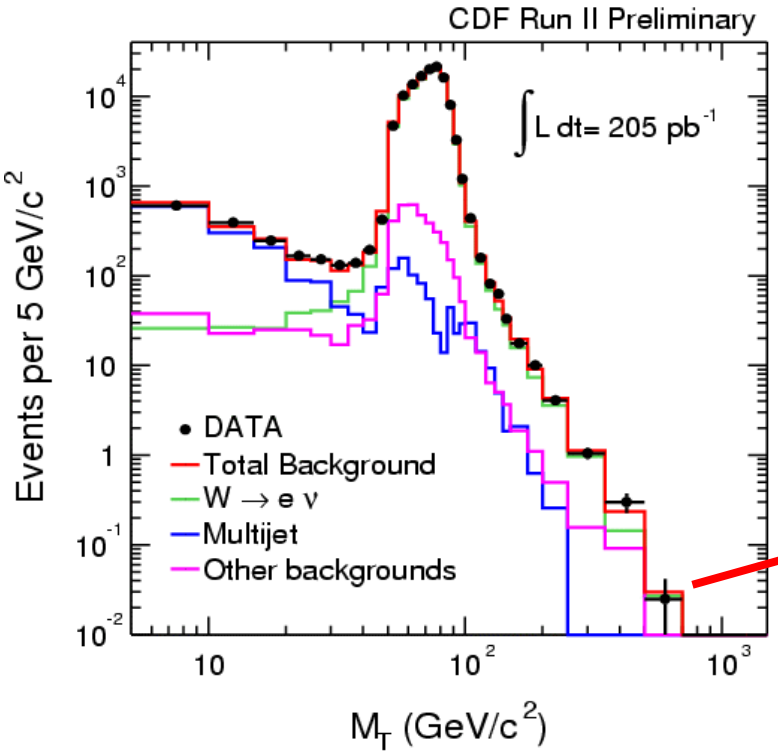


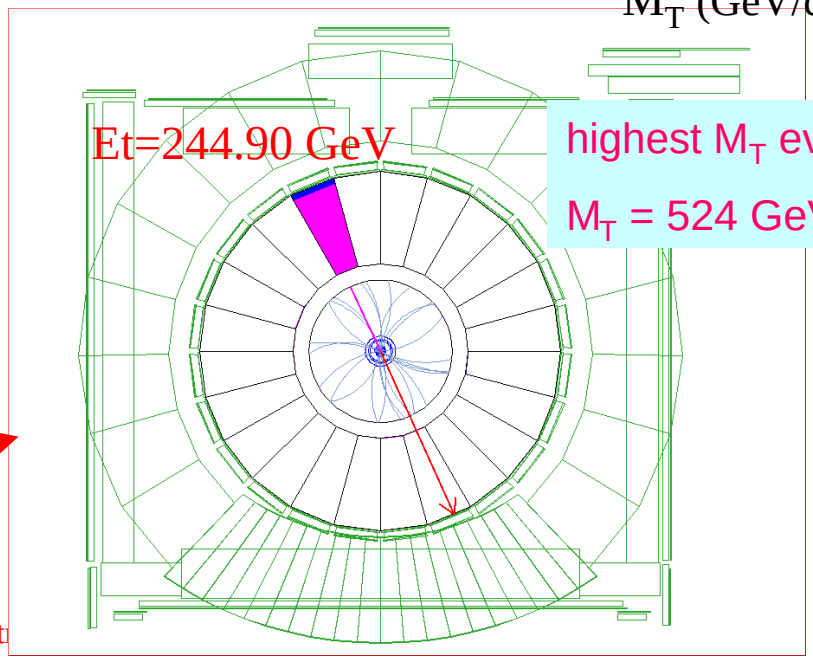
LEP2: excluded below line

W' Search in eν Channel

- W' additional charged heavy vector boson
- Appears in theories based on ext. of gauge group of SM
  - Left-Right symmetry models
  - Feature new gauge bosons, including a heavy right-handed W'
- Assume W'→eν , and ν is light and stable
  - Signature: high Pt e, high MET



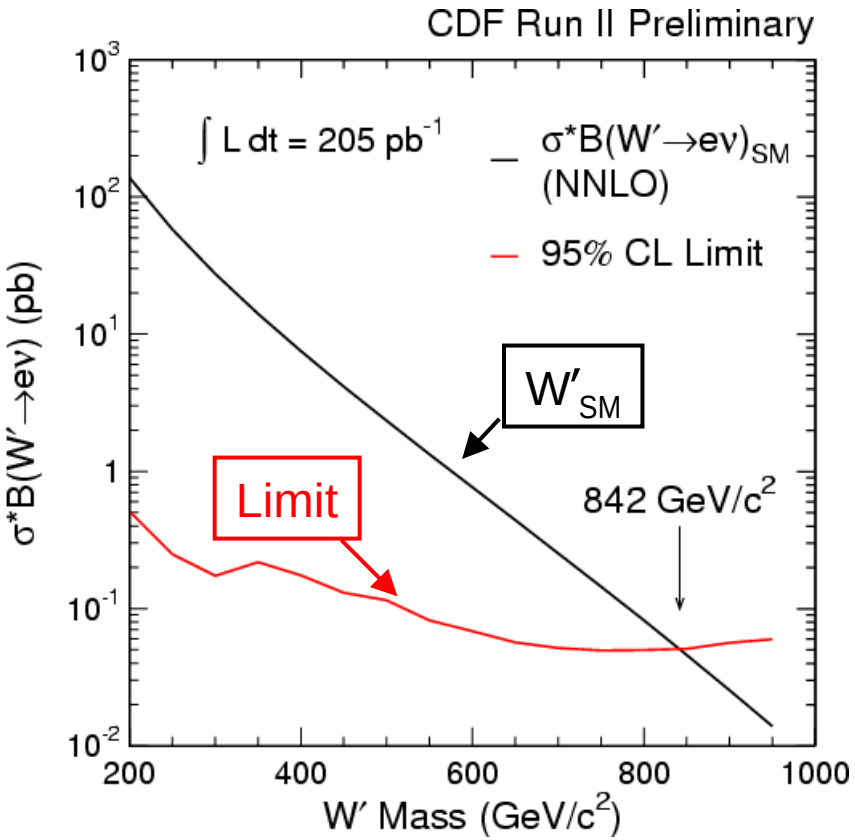




Wang, Tevat
ggs and New Phenomena at CDF

W' Search in eν Channel

- => No evidence for W'
- Set limits on W' production rate
- Use binned likelihood fitting method
- Two types of systematic are examined as function of M_T:
  - Event rate (dominant: PDF)
  - Signal shape (dominant: elec energy scale)
- σ*B(W'→eν) limit : ~50-100 fb for M(W')>500 GeV at 95% CL



Limit: $M(W'_{SM}) > 842$ GeV/c^2

Run I results (with the same assumptions):
$M(W'_{SM}) > 754$ GeV/c^2

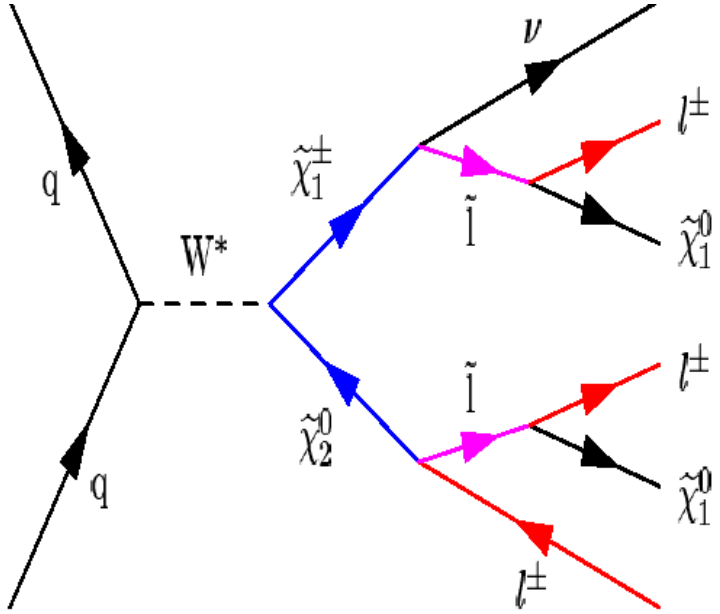
Search for SUSY in Multi-Lepton Final States

Searches for Chargino/Neutralino in Tri-Lepton

- Pair production of chargino/neutralino can produce multi-lepton and $\not{E}t$ in final state (assume R-parity conserved)
- Small contributions from SM processes in this signature

  ⇒Very clean, "Gold Plated" signature to find SUSY
- So far completed two channels:

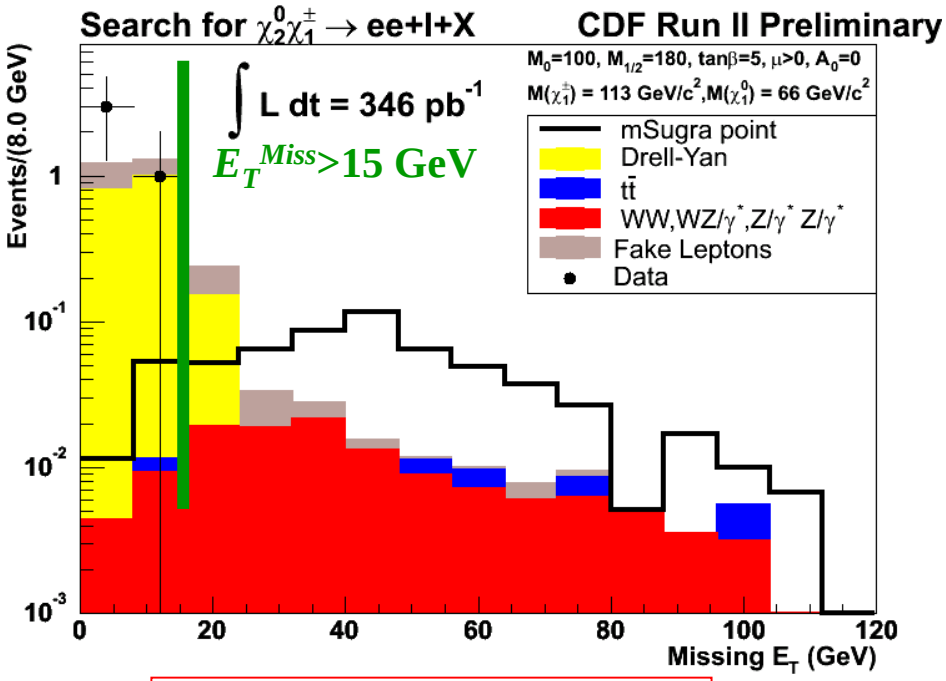
	High Pt	Low Pt
Lepton 1	e: >20 GeV	e: >10 GeV
Lepton 2	e: >8 GeV	e: >5 GeV
Lepton 3	e/m: >5 GeV	trk: >4 GeV



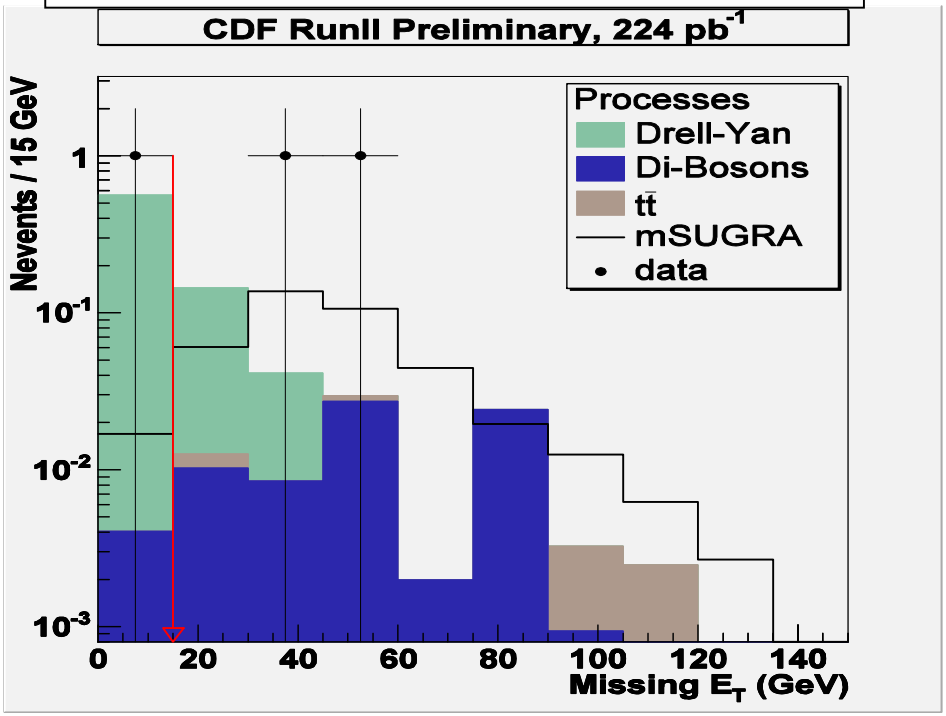
- Both analyses require :
  - MET > 15 GeV
  - l_1, l_2 not back-to-back => reduce DY
  - Veto events in Z and low mass resonances regions
- Low Pt analysis has higher backgrounds, require additional cuts

Searches for Chargino/Neutralino in Tri-Lepton

High Pt: Final selection (No MET cut)



Low Pt: Final selection (No MET cut)



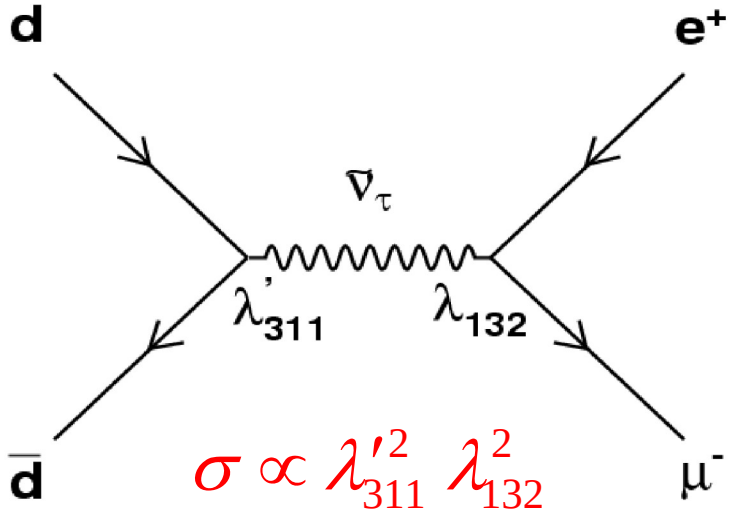
M_0=100 GeV, $M_{1/2}$=180 GeV
tan(β)=5, μ>0, A0=0

	"High Pt"	"Low Pt"
mSugra	0.5	0.5
Exp. Bkg.	0.16±0.07	0.36±0.27
OBSERVED	0	2

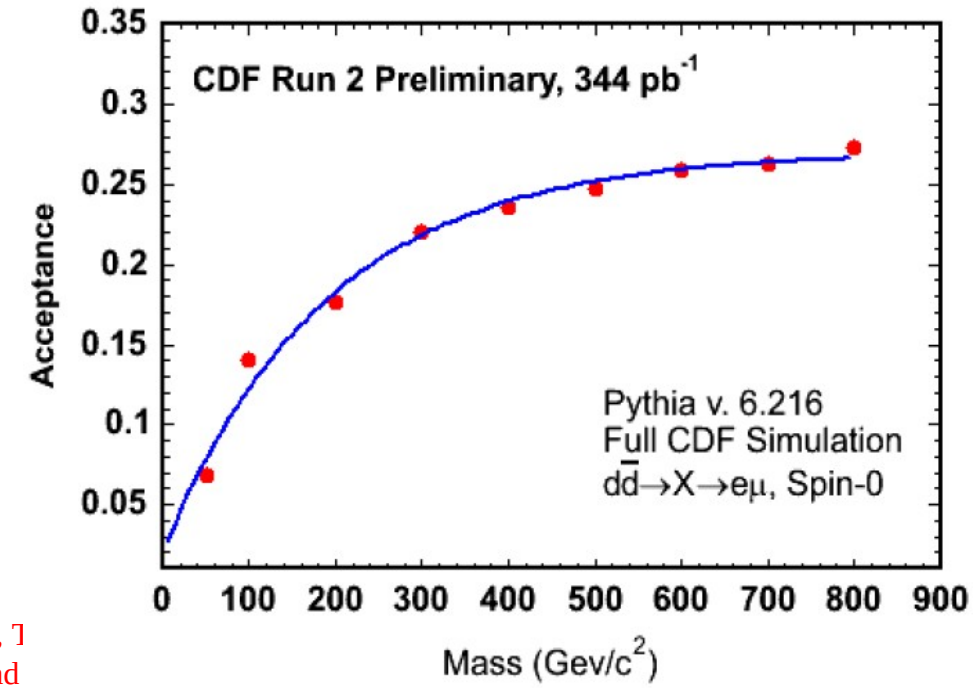
- To do :
  - Include μ channel (soon)
  - Extend to forward region (elec)
  - Combine results from all channels

Search for Scalar Neutrino (R-Parity Violation)

- Resonant slepton can be produced at Tevatron via λ' $\not{R}$p coupling
- Slepton can decay to two leptons via λ $\not{R}$p coupling
- CDF search for $\tilde{\nu}$ in the *e*-μ final state
- Selections :
  - Electron : Et>20 GeV
  - Muon : Pt>20 GeV
  - *e*,μ : opposite charged
- Relatively high acceptance in the region of interest
- Very clean signature
  - Dominant background: $Z \rightarrow \tau\tau$

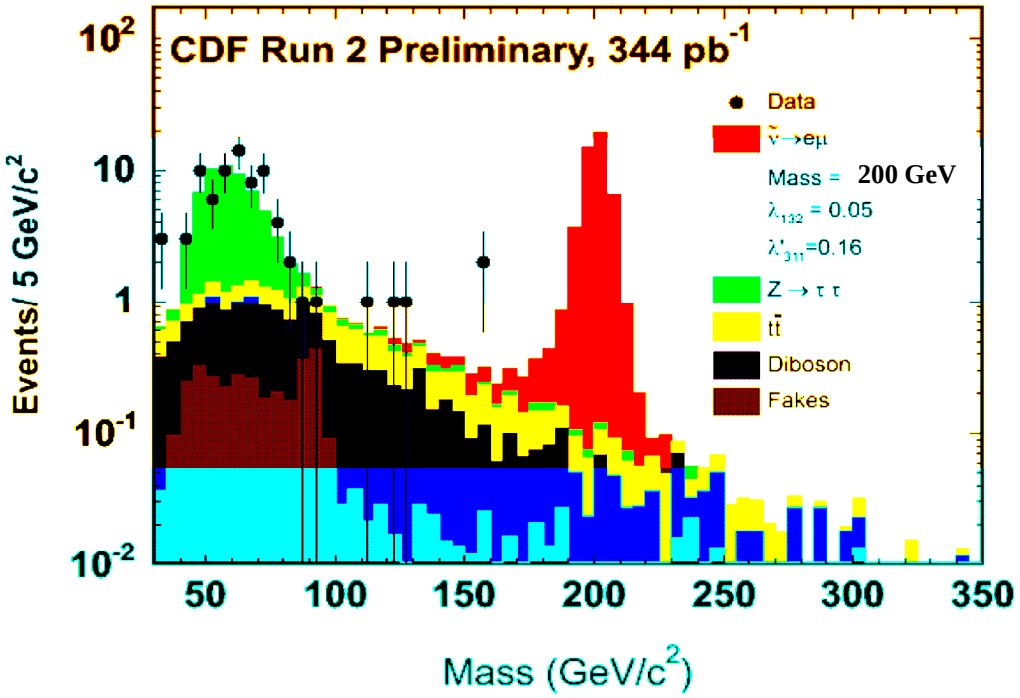


$$\sigma \propto \lambda'^{2}_{311}\,\lambda^{2}_{132}$$



Search for Scalar Neutrino (R-Parity Violation)

After all cuts:

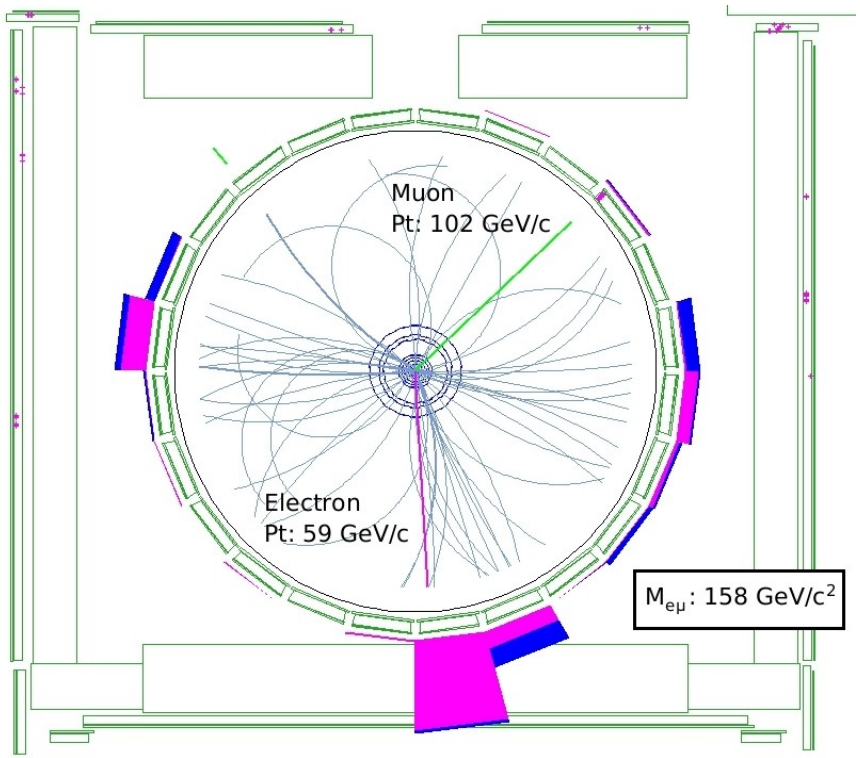


- Nobs=77, Nexpect=71.3±1.8(stat)
- For M($e\mu$)>100 GeV
  - Nobs=5, Nexpect=8.0±1.1(stat)
- Backgrounds:
  - $Z \to \tau\tau$, ttbar, Diboson

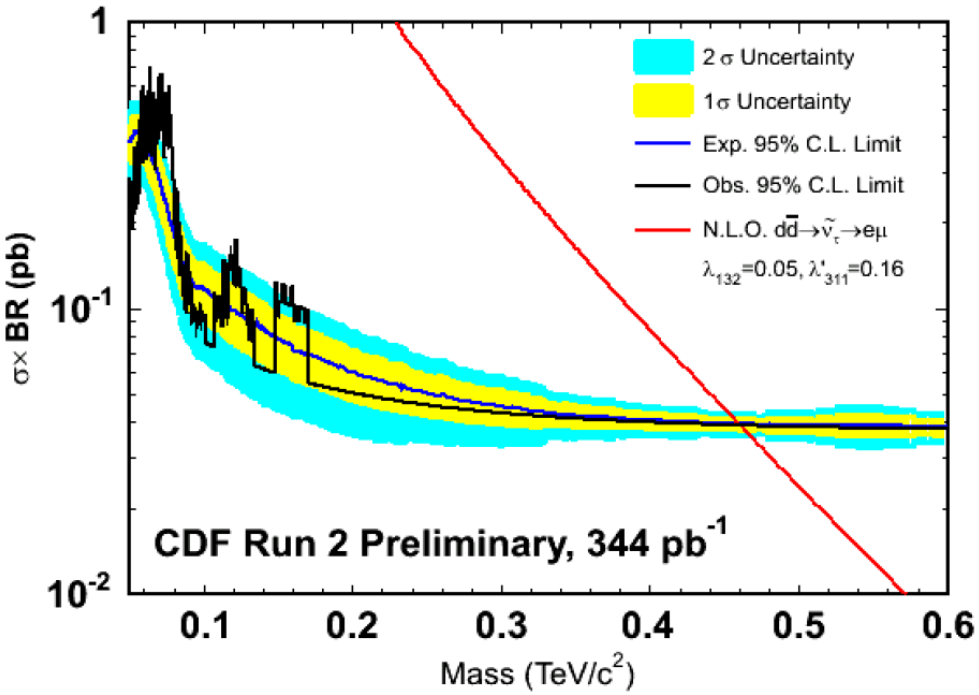
Highest M($e\mu$) event :

M($e\mu$) = 158 GeV

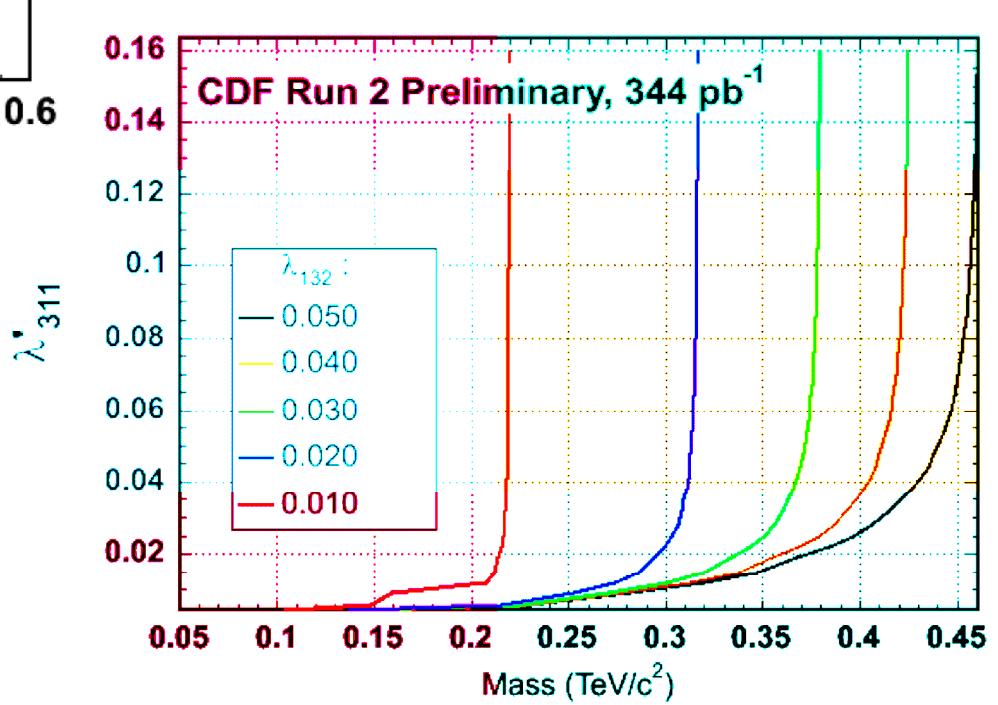
Elec Et=59 GeV, Muon Pt=102 GeV



Search for Scalar Neutrino (R-Parity Violation)



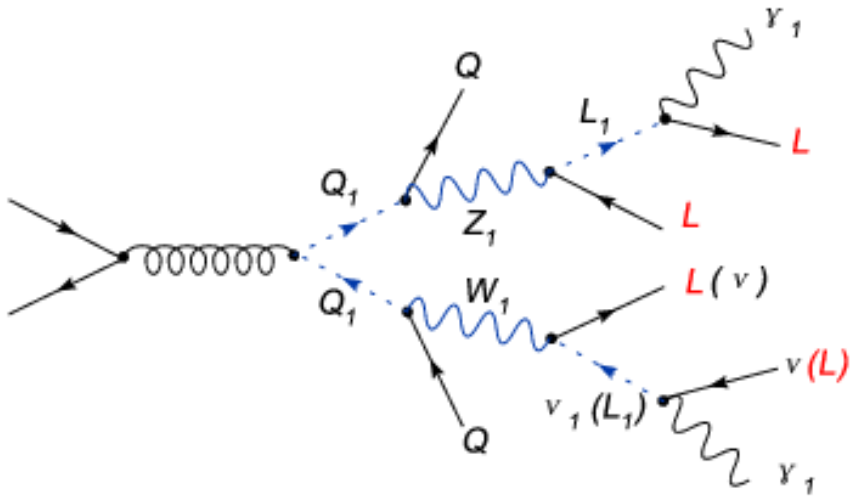
- Interpret x-section limit:
  - For λ_{132}=0.05 λ'_{311}=0. 16
    - M>460 GeV
  - Can set a limit in 2D λ'_{311} vs M($\tilde{\nu}$)



Search for Universal Extra Dimension (UED)

•UED (Appelquist, Cheng, Dobrescu: Phys. Rev. D64, 035002 (2001)) :

- All particles live in a (4+n) dimensional space. SM fields can propagate into the extra compact dimensions of size R (~TeV^{-1})
- 1st KK excitation of the SM particle undergoes cascade decays into its SM counterpart and the lightest KK particle (LKP)
  - LKP: stable and interact weakly (like LSP in SUSY)
- Pair production of KK particles could results in final states with multiple leptons and MET
  - Leptons are usually soft, due to cascade decays



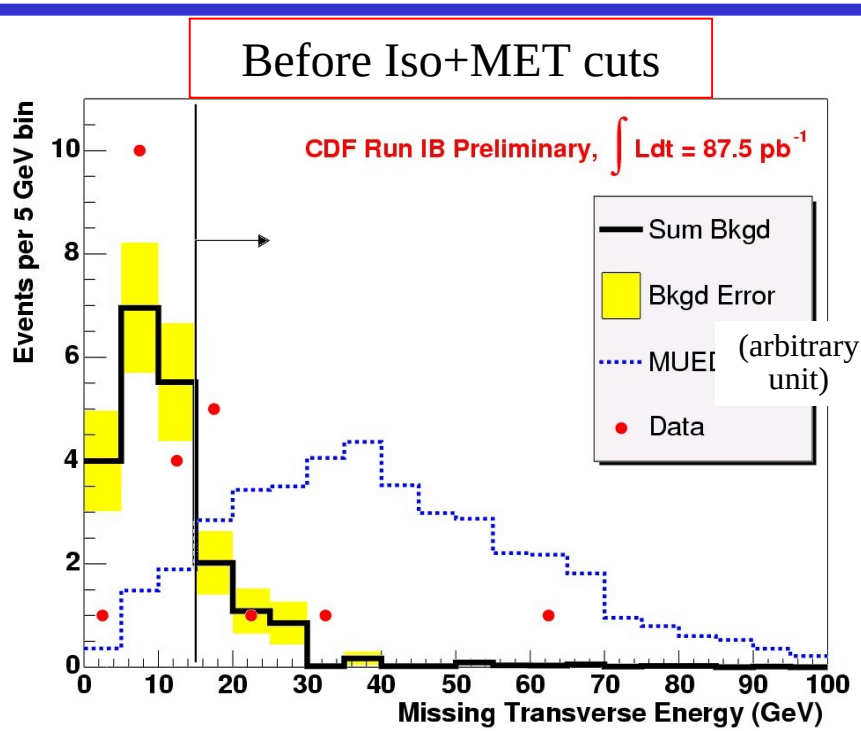
Q_1, Z_1,W_1,L_1,ν_1 counterparts of q,Z,W,*l*,ν

•In minimal UED (MUED) scenario:

- Has 3 free parameters (R, Λ, m_h)
  - R : size of extra dimensions
  - Λ : radiation correction cut off
  - m_h : SM Higgs mass

Search for Universal Extra Dimension (UED)

- CDF searched for UED using Run 1 data (87.5 pb^{-1}), requiring at least three leptons
- SM backgrounds :
  - bb-bar/cc-bar, tt-bar,WZ, ZZ } real multi-lepton
  - DY, WW } di-lepton + fake
- Selections:
  - ≥3 leptons (e,μ) (Et(pt) > 11,5,5 GeV)
  - At least one pair e+e-, μ+μ-
  - Leptons not back-to-back (reduce DY)
  - Remove resonances, bb/cc
  - Lepton isolated, MET>15 GeV
- Consider only "non-μμμ" channels
  - Large fraction of BG with "μμμ" signature from bb/cc



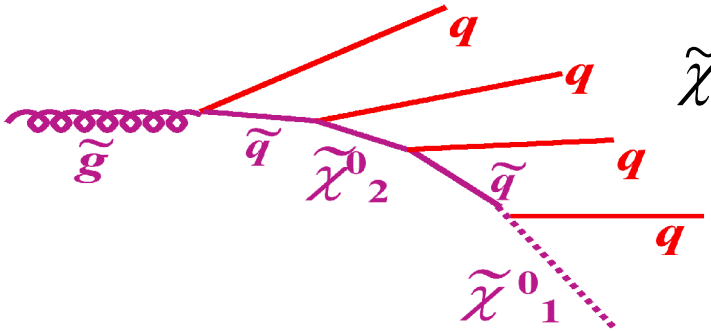
- From "non-μμμ" channel,
  - Nexpect=0.05±0.005, Nobs=0
  - Nsignal=0.38 (R^{-1}=350 GeV, ΛR=20, m_h=120 GeV)
- @ 95% CL, upper limit cross section for total KK production = 7.9 pb
  - **⇒ R^{-1} > 280 GeV (ΛR=20, m_h=120 GeV)**

Search for New Physics in MET+Jets

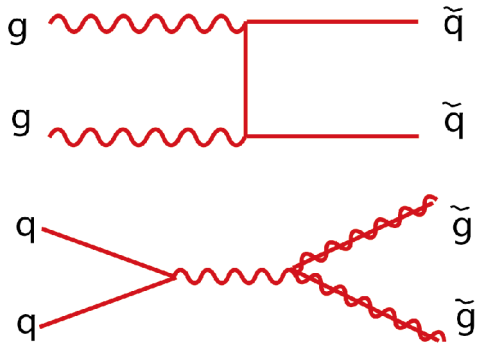
Search for Squarks/Gluino in MET+Jets

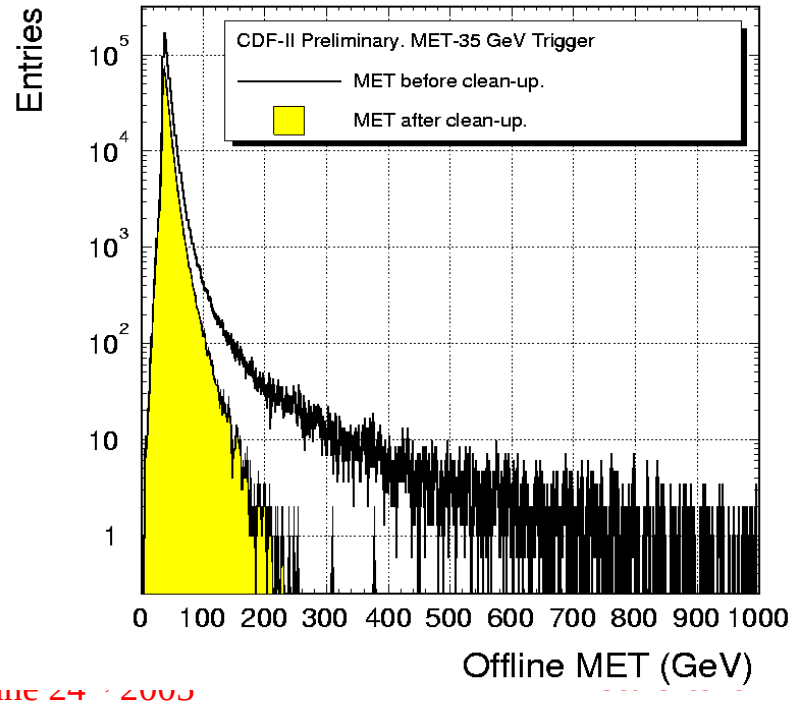
- Light colored sparticles($\tilde{q},\tilde{g}$) can be copiously pair produced at Tevatron

- Decays of $\tilde{q},\tilde{g}$ may produce multiple jets and large $\not\!\!E_T$ (if Rp is conserved)



$\tilde{\chi}_1^0$: LSP

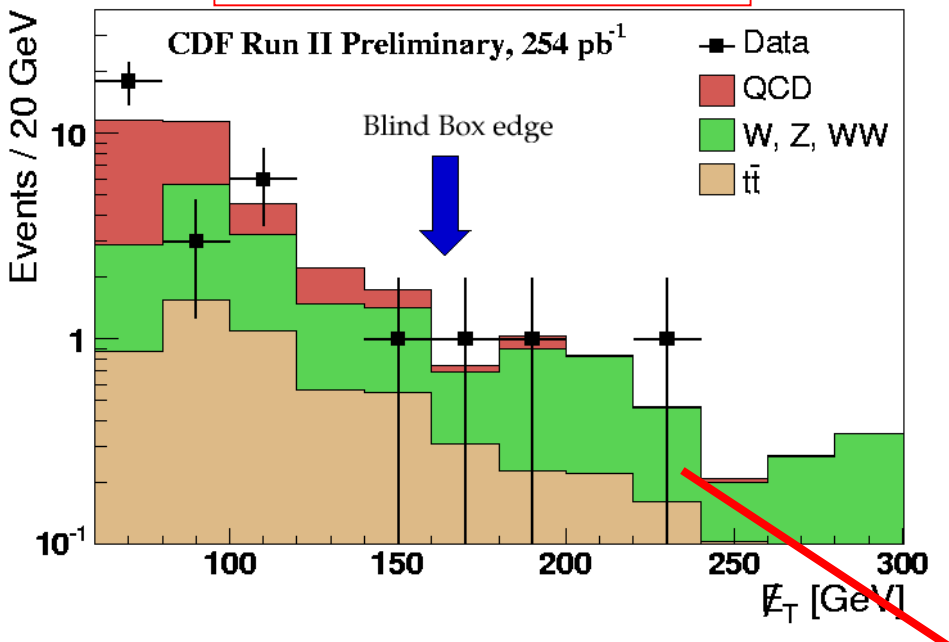




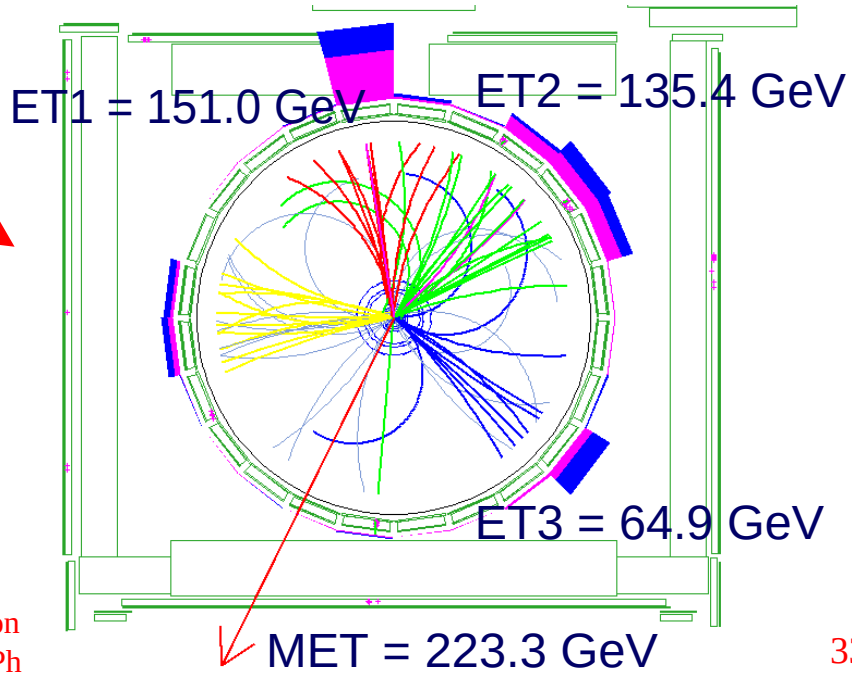
- CDF performs direct search for $\tilde{q},\tilde{g}$ using $\not\!\!E_T$ + jets data sample (~254 pb-1)
- Challenging analysis:
  - Signal is buried under enormous QCD multi-jet background
  - Missing energy mis-measurements
    - Jet energy mis-measured
    - Non-collision backgrounds (beam halo, hot towers..)

Search for Squarks/Gluino in MET+Jets

All cuts, except MET cut



- Selection:
  - ≥3 jets (125, 75, 25 GeV)
  - MET>165 GeV, H_T>350 GeV
  - MET not aligned w/ jets
  - No charged leptons (reduce EW BG)
- Nobs=3, Nexpect(SM)=4.2±1.1
  - Expect ~0.7-4.8 SUSY events in SUSY space explored (M(q,g)~380 GeV)



- Scan parameter space, will set limit soon

Search for the Higgs Boson

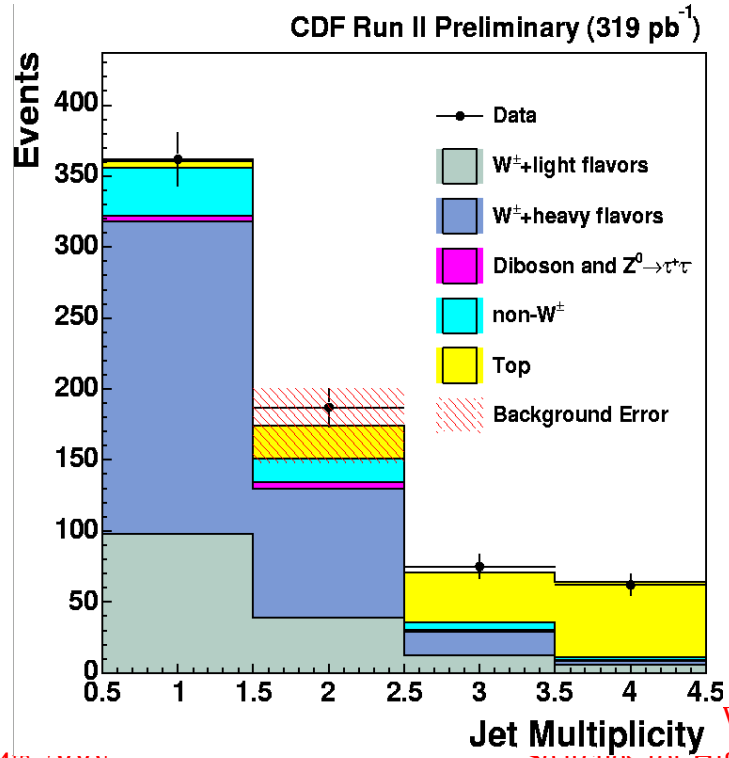
Searches for SM Higgs

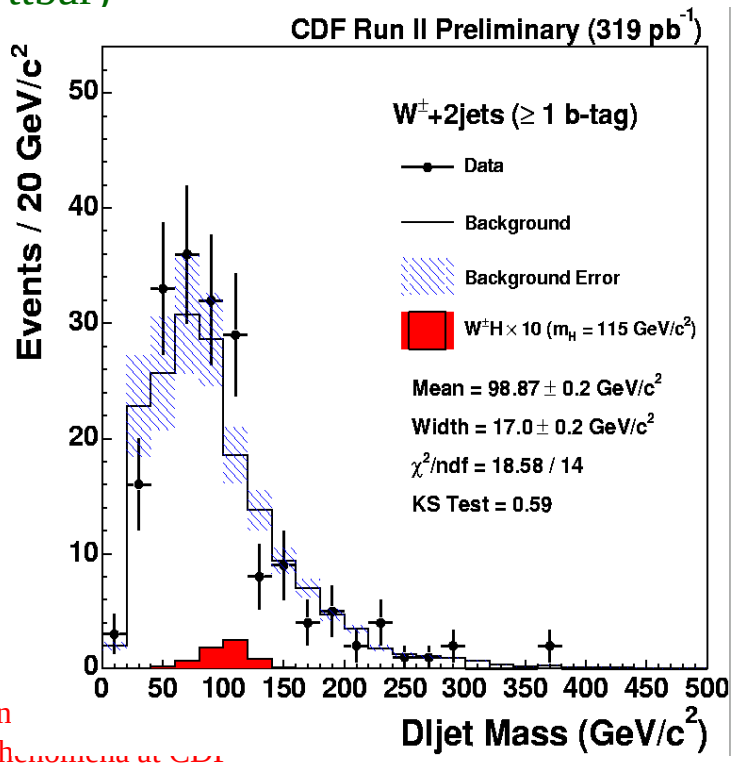
- CDF search for SM Higgs in several channels :

$WH \to l\nu b\bar{b}$	$H \to WW$
$ZH \to \nu\nu b\bar{b}$	$WH \to WWW^*$

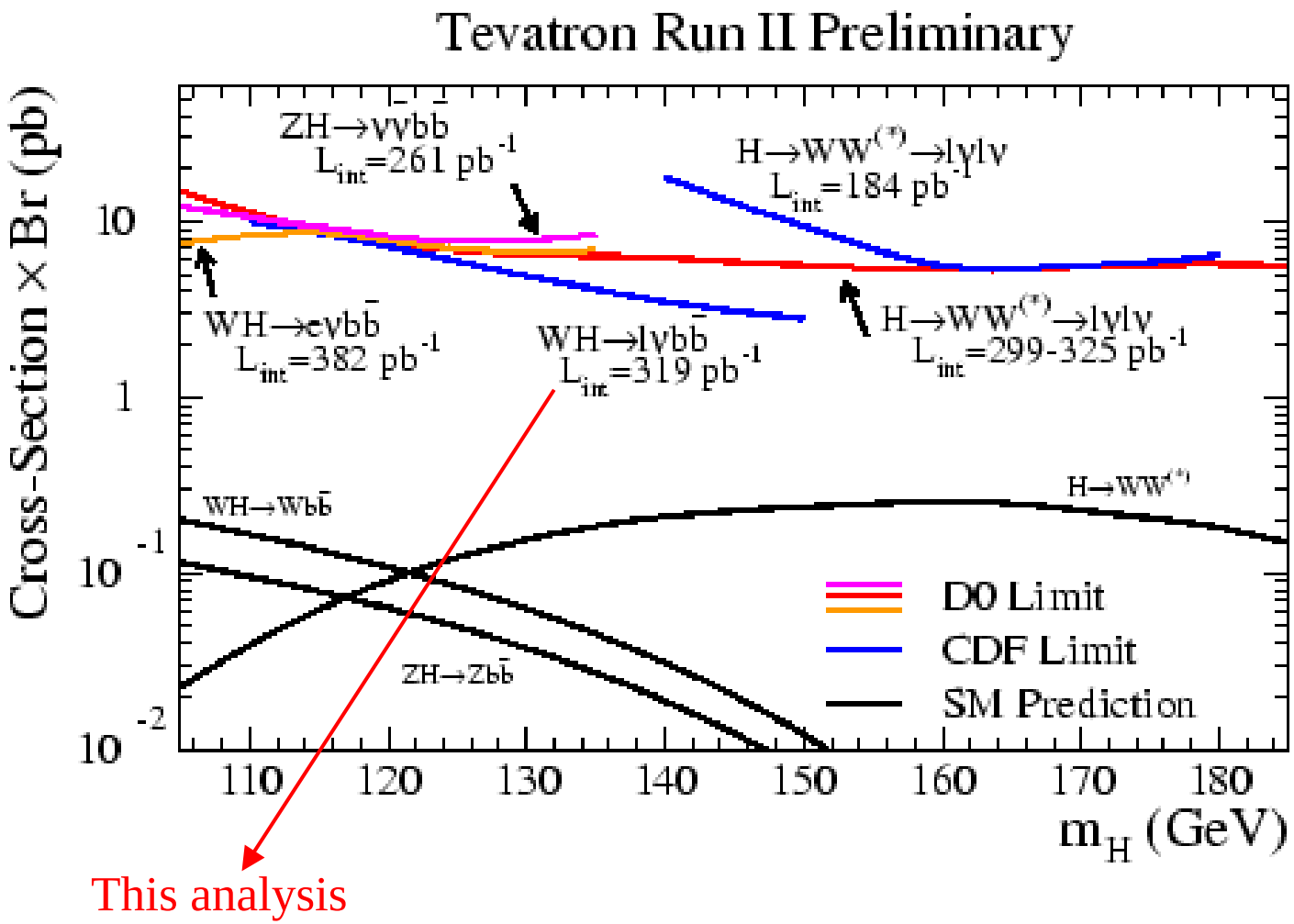
1st results soon

- NEW updated results from $WH \to l\nu b\bar{b}$
- Selection:
  - High pt lepton data (L=319 pb^{-1})
  - One high pt central *e* or μ, large MET (MET>20 GeV)
  - 2 jets (at least one is tagged as b-jet)
  - Veto events w/ >1 lepton (suppress ttbar)





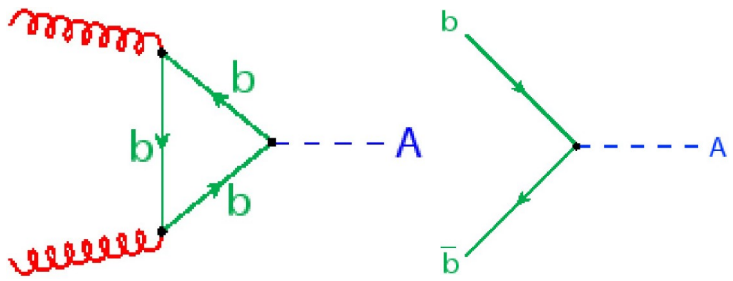
Searches for SM Higgs

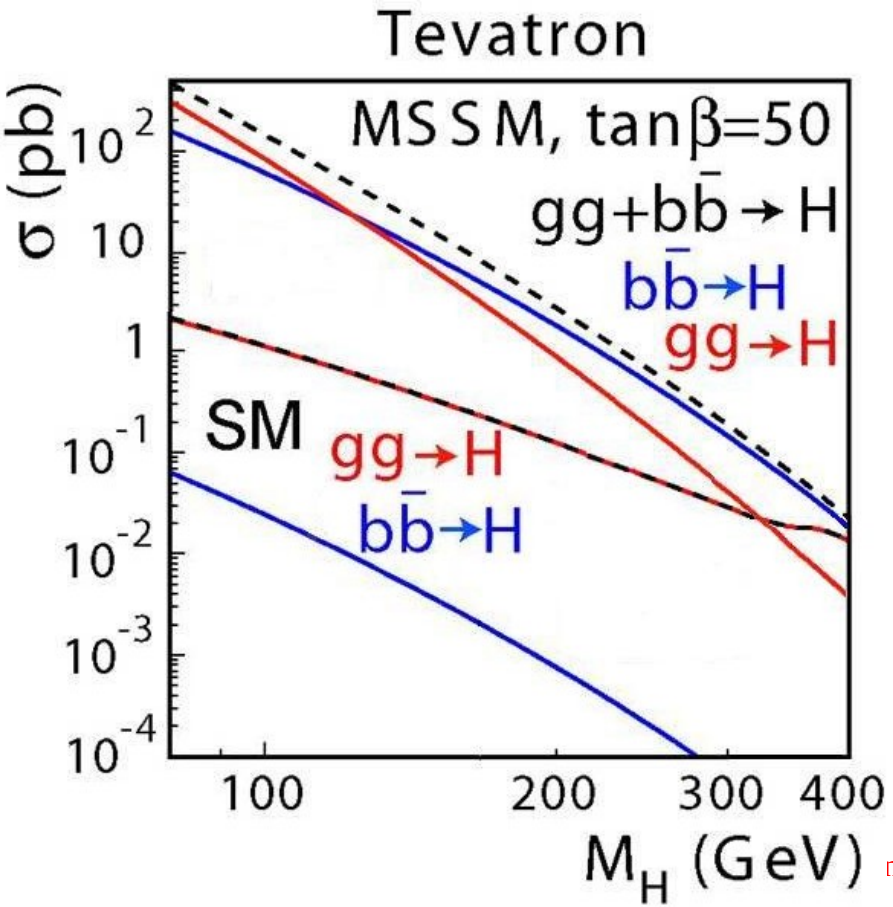


This analysis

MSSM Higgs→ττ

- Higgs production rate in MSSM can be much larger than in SM at high tanβ
  - Coupling of Higgs to down-type fermions are enhanced by factor of tanβ
  - $\sigma(pp \to H/A/h) \propto \tan^2\beta$



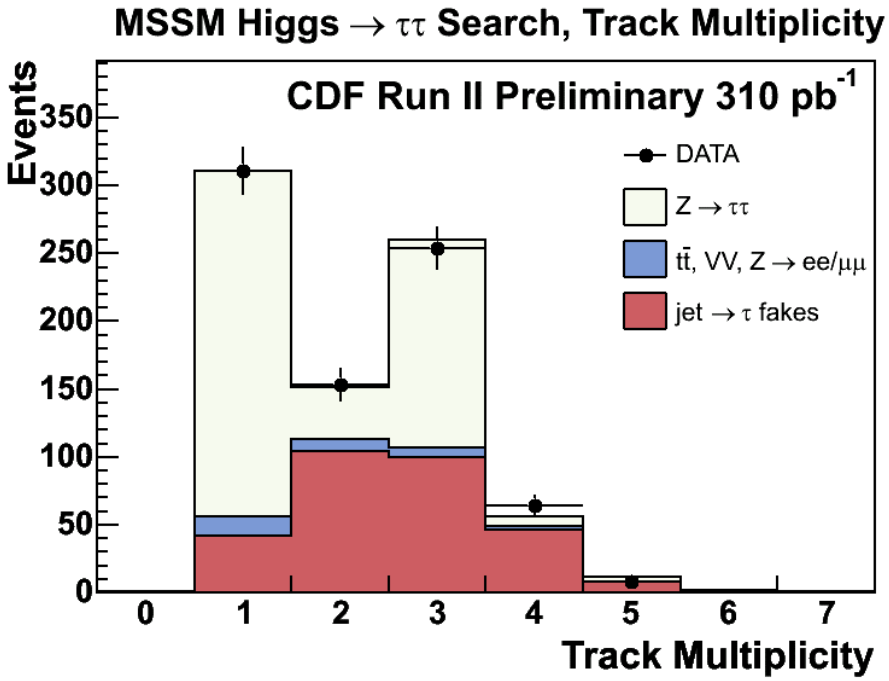


- Br(ϕ→bb)~90%
  - gg,bb→ϕ→bb: need to overcome large QCD BG
- Br(ϕ→ττ)~10%
  - gg,bb→ϕ→ ττ: overcome much smaller SM BG

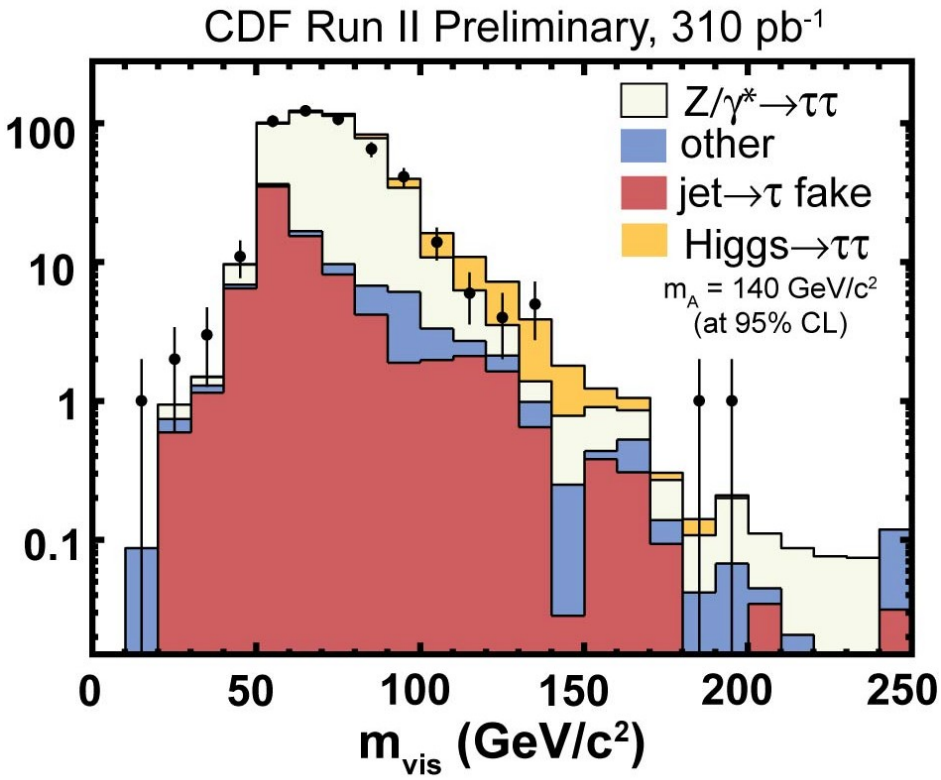
Promising channel at Tevatron

MSSM Higgs→ττ

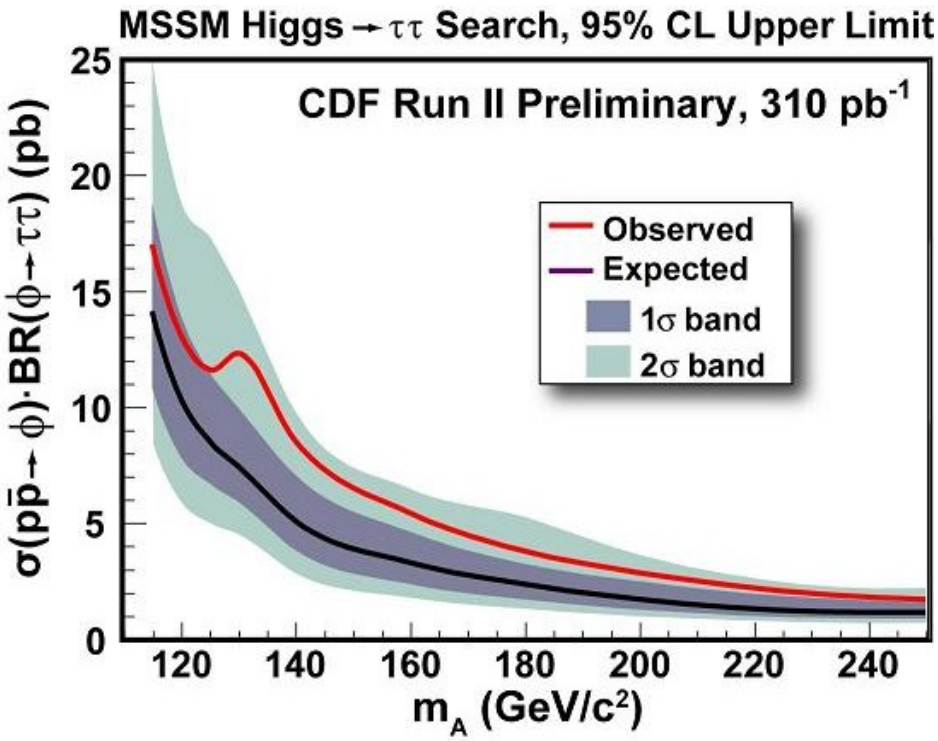
- Selections:
  - –Lepton (e/μ) p_T>10 GeV
  - –Had. Tau p_T>15 GeV
  - –H_T ($|P_T(e/\mu)|+|P_T(h)|+|MET|$)>50 GeV
  - –Anti-W cut
- Backgrounds:
  - –Z→ττ
  - –W+jets, QCD: jets faking τ
  - – ttbar, diboson, Z→ee/μμ



MSSM Higgs→ττ

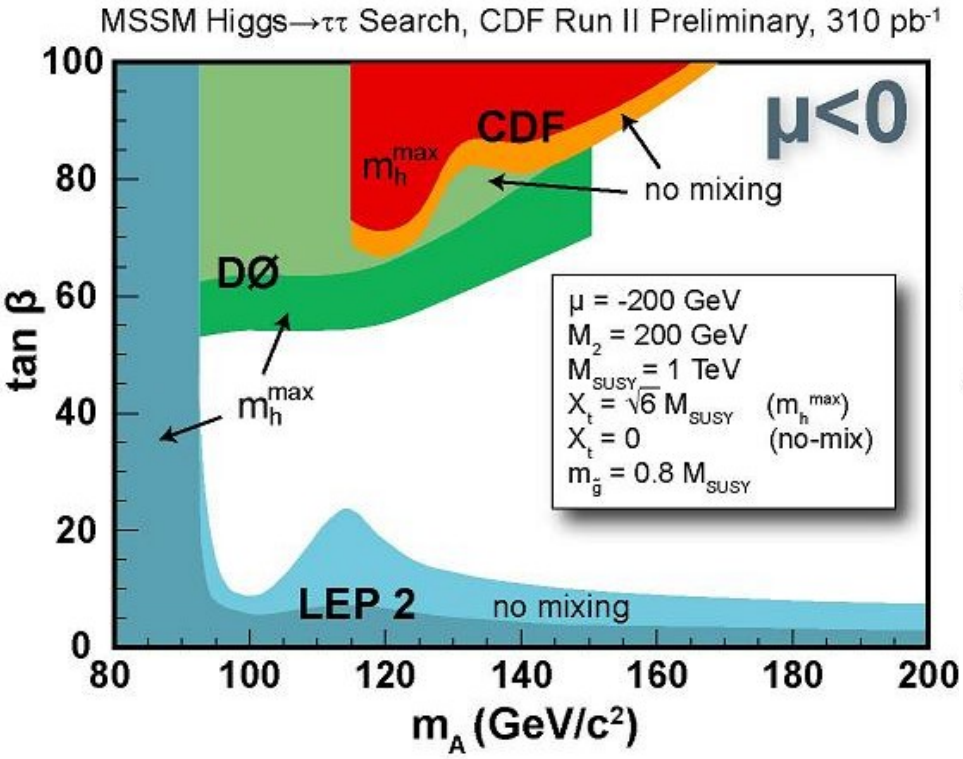


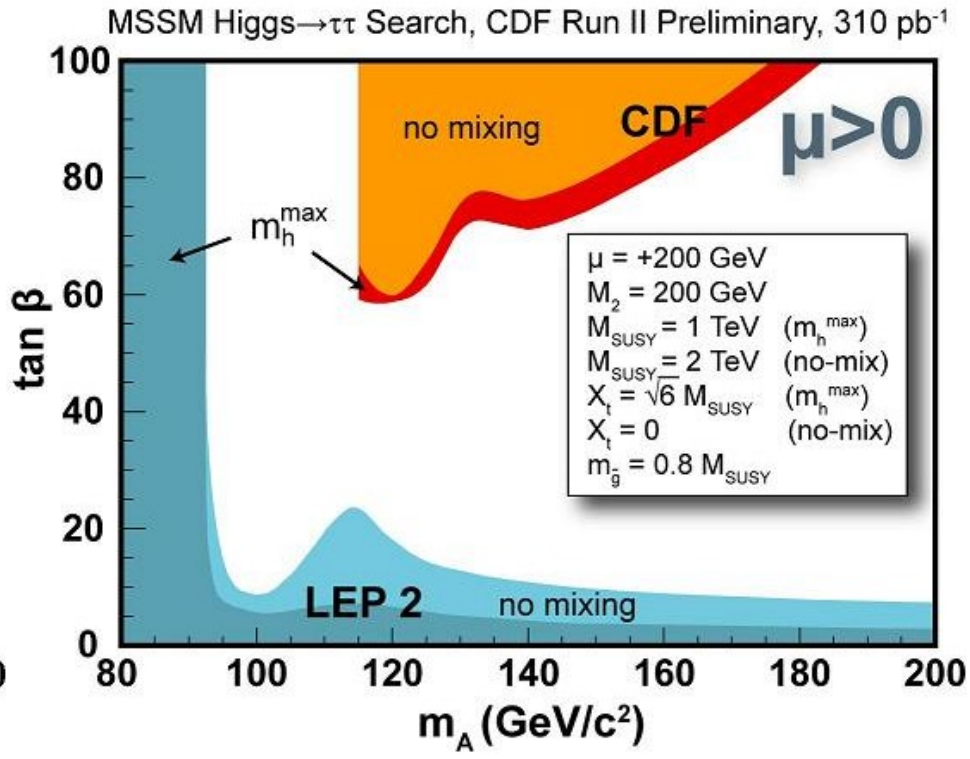
- Good agreement between data and SM expectation in low mass region
- High mass events (m>120):
  - –Exp. SM = 8.4 ev, Obs. = 11
- Limit:
  - –Fit mass spectrum for (Bkg+Z+A)



MSSM Higgs→ττ

•Interpret cross-section limit in terms of tanβ and m_A:





•For μ<0

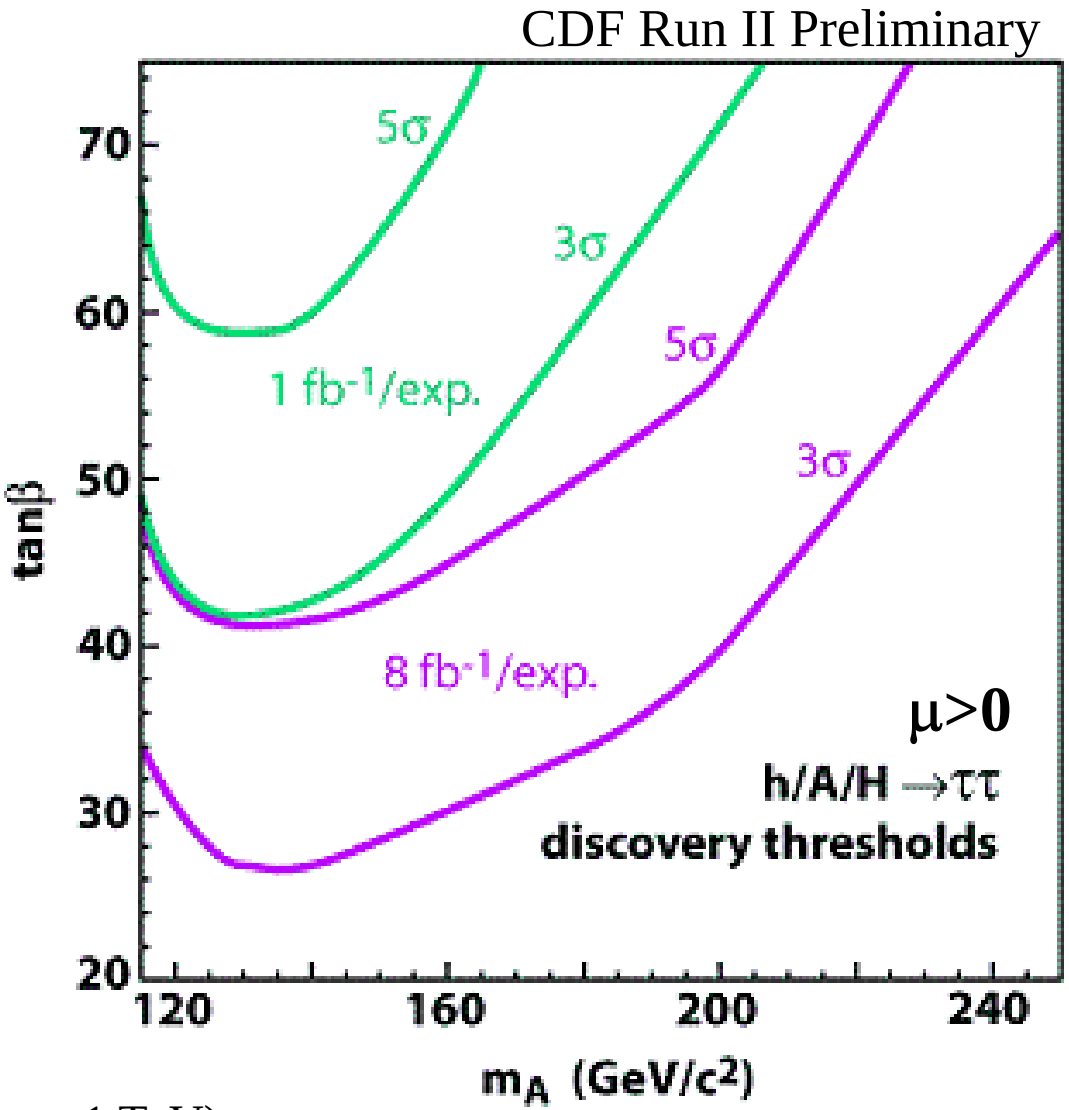
–Complementary to SUSY Higgs bbb(b) mode (from DØ)

•For μ>0:

– ϕ→ττ channel extends to higher higgs mass and lower tanβ region than for μ<0

MSSM Higgs→ττ

- Projection of the reach of this search in $\phi \rightarrow \tau\tau$ to higher luminosity



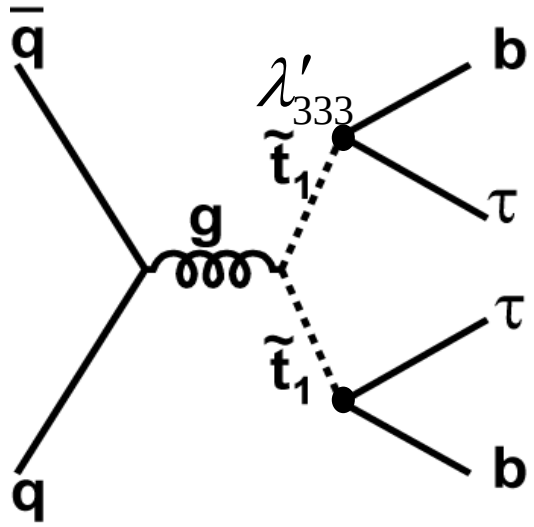
M. Carena et al., hep-ph/0202167:
m_h^{max}: μ=+200, $A_0=\sqrt{6}M_{SUSY}$ (we use M_{SUSY}=1 TeV)
Min mix: μ=+200, A_0=0

Summary

- CDF has an extensive program in searches for new physics at the Tevatron
  - Exploring many exotic new phenomena (e.g. Extra Dimensions, Champs, Magnetic Monopoles, Stop, Sbottom …..)
  - Systematic approach in several other searches
    - Z' (*ee*,μμ,ττ,….spin 0,1,2 ..)
    - Higgs (different production and decays channels)
- Although have not yet make new discoveries w/ current analyzed data
  - Have developed/sharpen our analysis tools
- Have entered the **fb^{-1} era** !
  - **VERY EAGER to look at these new data !!!**

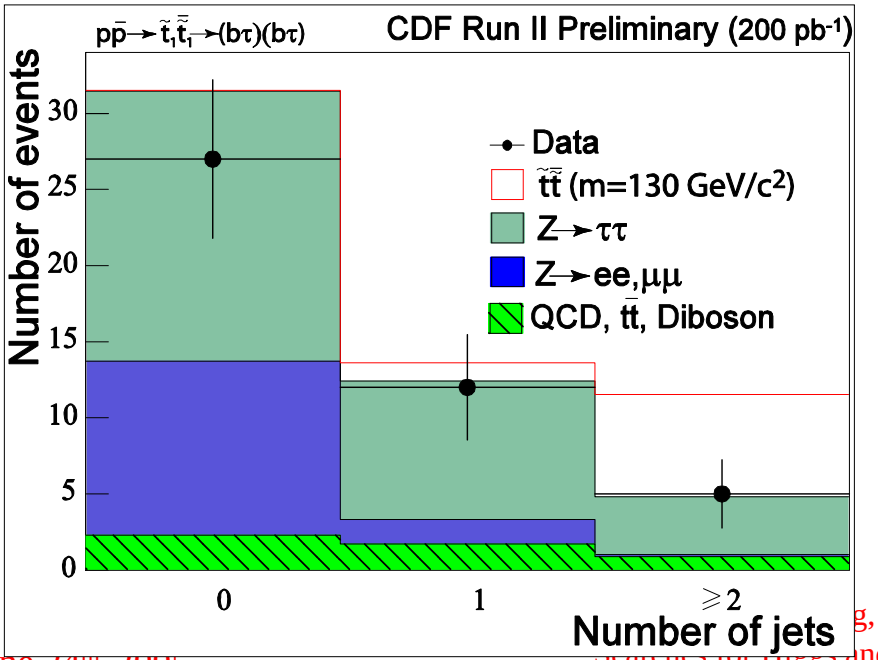
Search for Stop Quark in R-Parity Violation

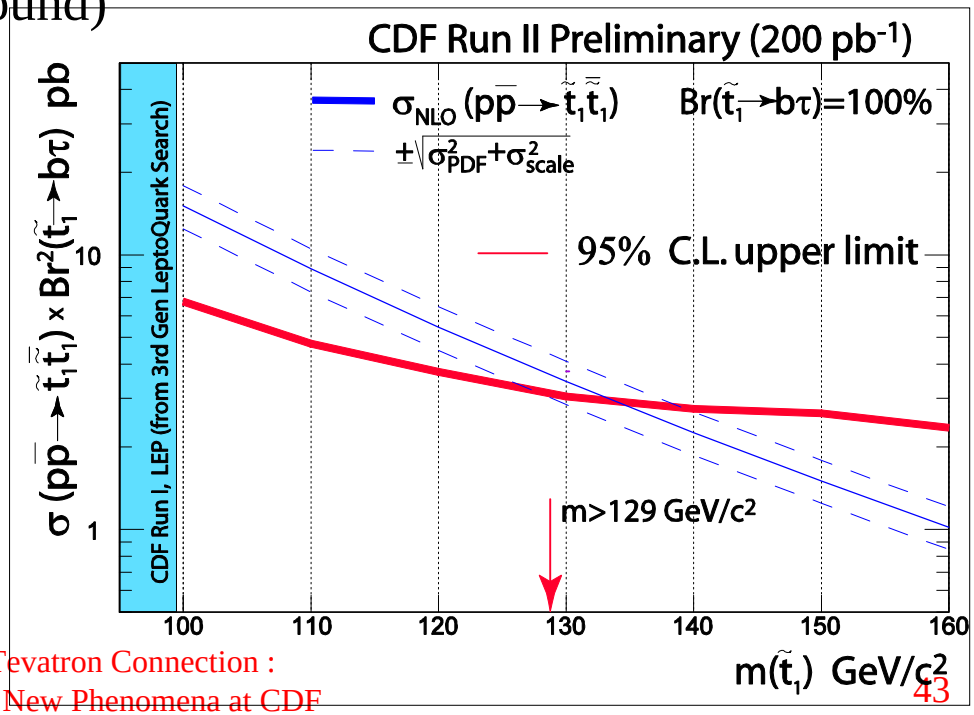
- If stop quark is light => can be pair produced at Tevatron
- If $\not R_p$ is allowed, and $\lambda'_{333} \neq 0$, => $\tilde{t}_1 \to b\tau$
- Assume Br($\tilde{t}_1 \to b\tau$) = 100%



Selection:

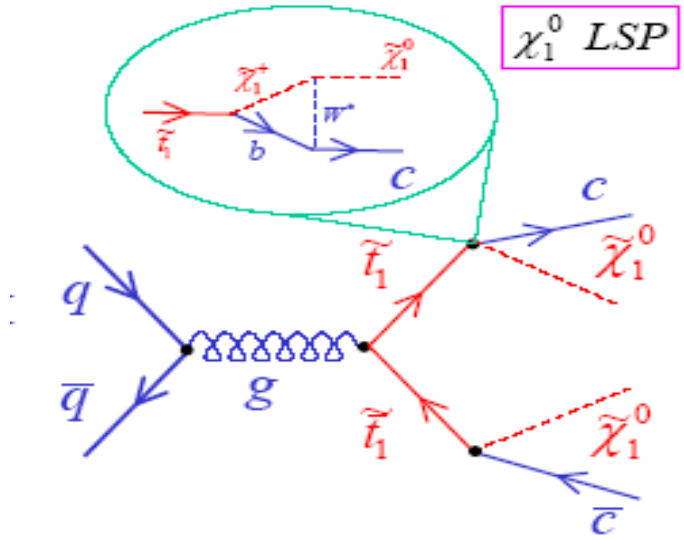
- 1 lepton (e or μ), 1 hadronic tau
- ≥ 2 jets
- $M_T(l, \text{MET}) < 35$ GeV (remove W background)

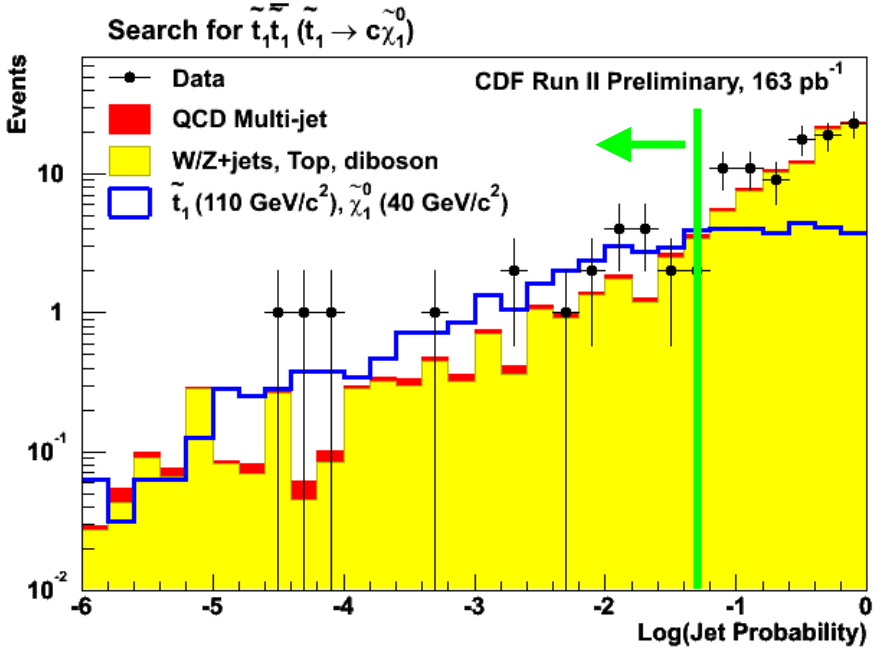




Search for Stop Quark in MET+Jets

- Stop quark is often predicted to be light due to large top Yukawa coupling
- Depending on the stop's mass w.r.t. other sparticles, assume BR($\tilde{t}_1 \to c\tilde{\chi}_1^0$)=100%
- Signature :
  - 2 jets + Large MET
  - Tag charm jets with JetProb





- JetProb:
  - Compute probability a jet originates from primary vertex (based on track impact parameter)

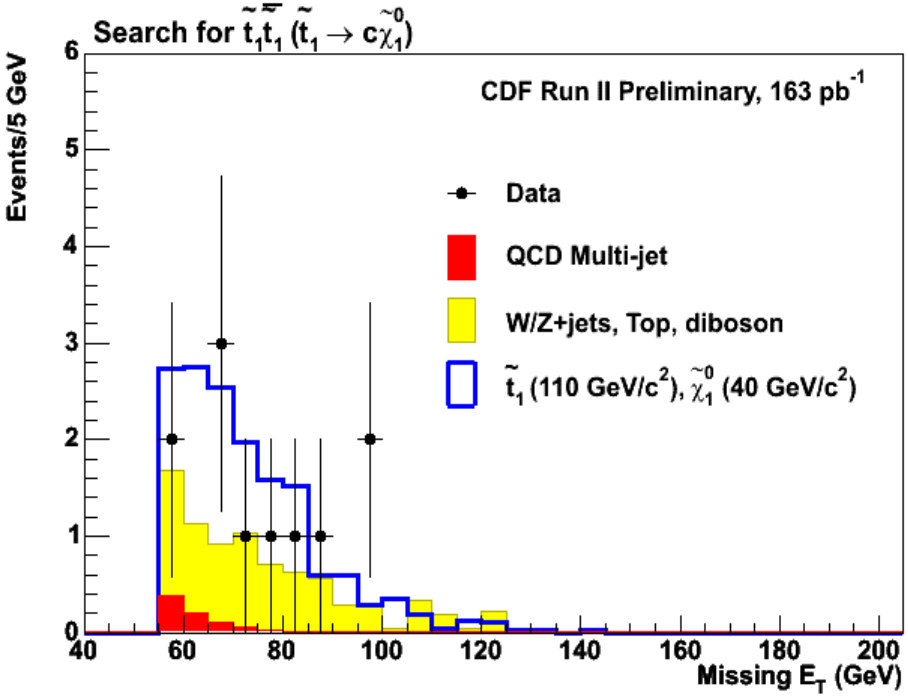
All selection cuts applied, except tagging charm jets

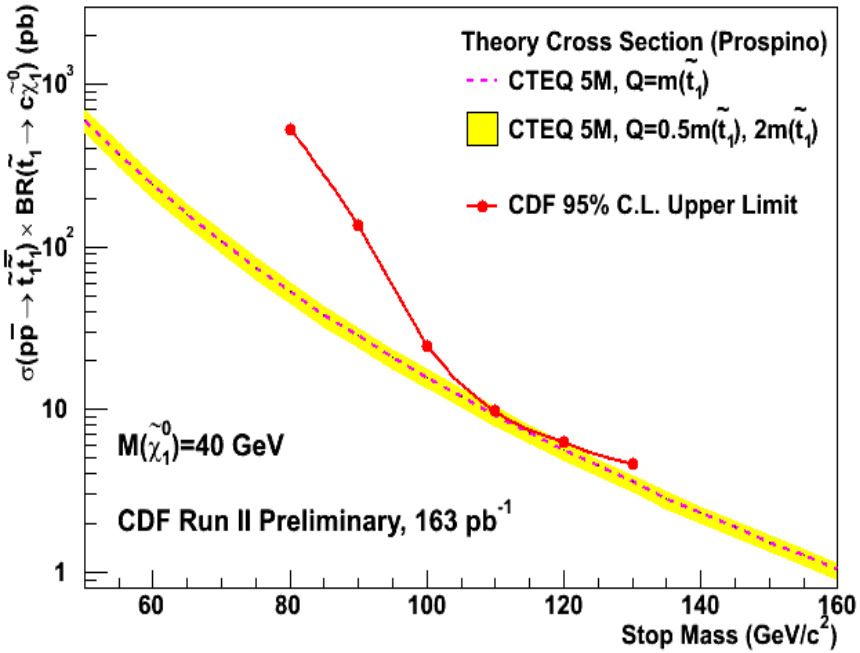
Search for Stop Quark in MET+Jets

	Exp.	Obs.
Pre-tag	105 ± 12	119
Tag (silicon)	8.3 ± 2.3	11

- No excess, set limit
- Benchmark assuming

$$BR(\tilde{t}_1 \to c\tilde{\chi}_1^0) \sim 100\%, m_{\chi_1^0} = 40\text{GeV}/c^2$$





Search for Stop Quark in MET+Jets

	Exp.	Obs.
Pre-tag	105 ± 12	119
Tag (silicon)	8.3 ± 2.3	11

- No excess, set limit
- Benchmark assuming

$$BR(\tilde{t}_1 \to c\tilde{\chi}_1^0) \sim 100\%, m_{\chi_1^0} = 40\text{GeV}/c^2$$